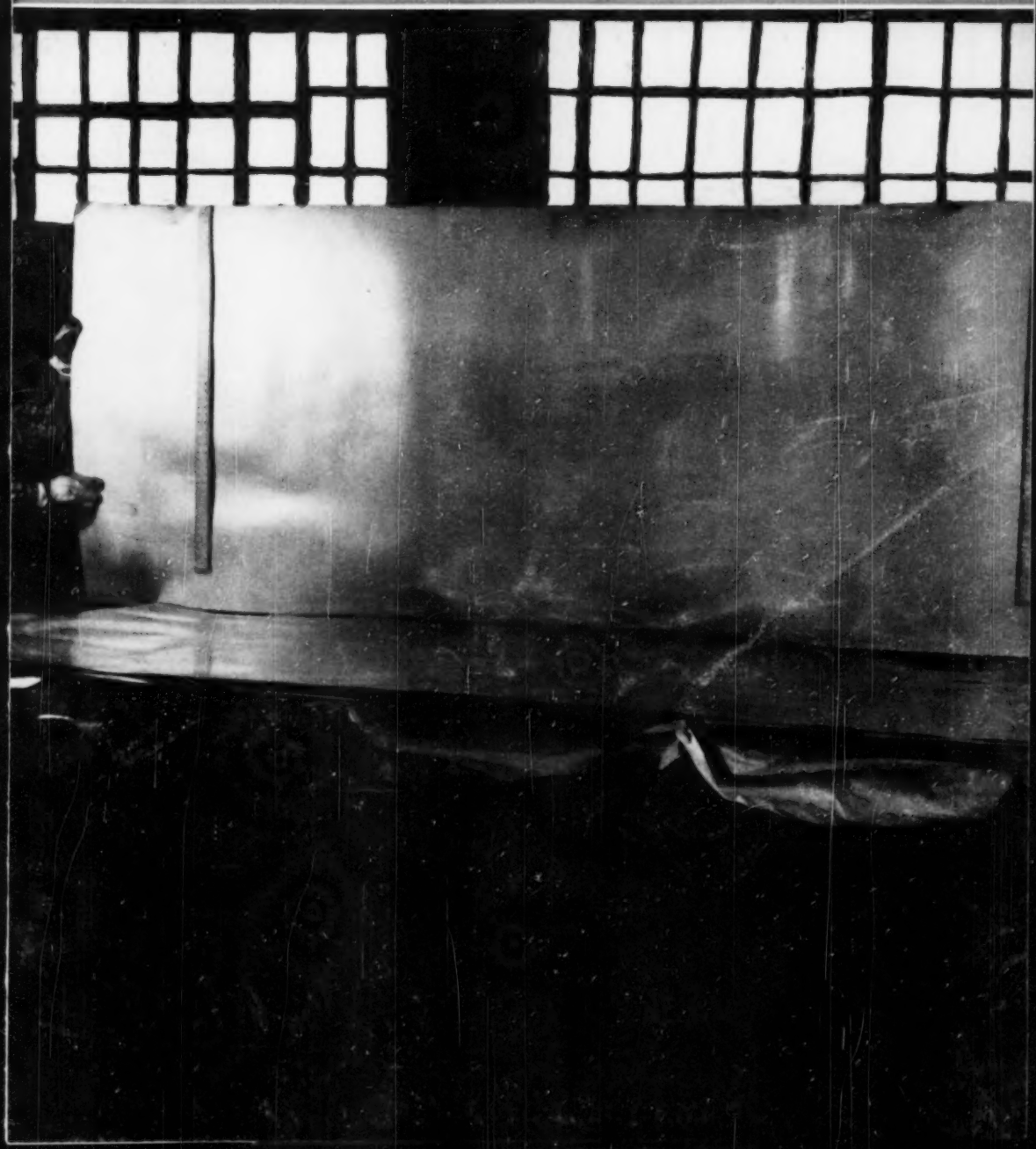
JULY 1950

Journal of METALS



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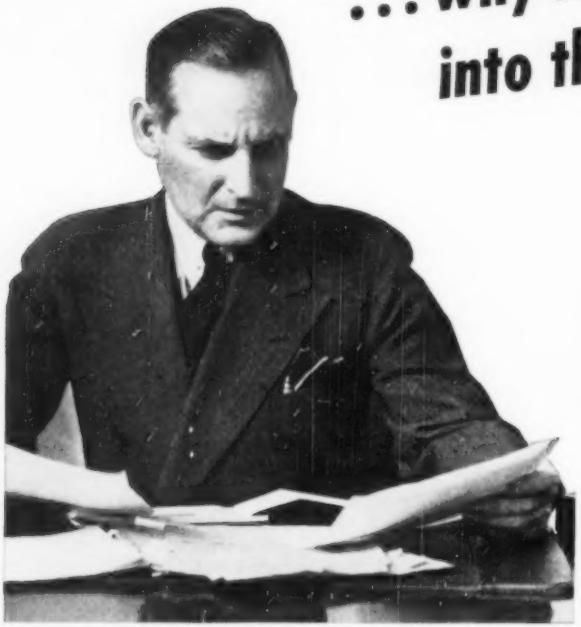

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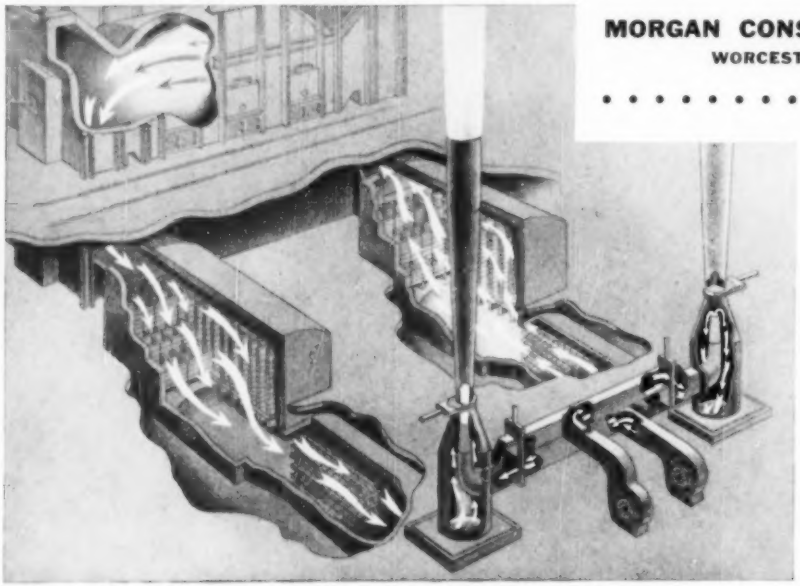

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VOL. 188, NO. 7 JULY, 1950

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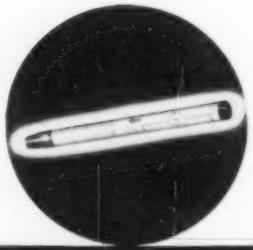

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Authors In This Issue

Sidney Siegel (p. 916) has been Development Engineer of the General Plate Div. of the Metals Controls Corp., Attleboro, Mass., since 1945. Previously he served on the Manhattan Project in research and development work, and as research metallurgist in the Naval Research Laboratory at Washington, D. C.

Sidney Siegel

He was born in Roxbury, Mass., and received a B.S. in Met. from MIT in 1943. He is an AIME member. Near his home in Attleboro, he hunts little white balls and replaces divots.

Paul Pietrokowsky (p. 933). See JOURNAL OF METALS, December, 1949.

T. E. Tietz (p. 933). See JOURNAL OF METALS, December, 1949.

Charles B. Jordan (p. 943), a native of Akron, Ohio, is a Research Engineer in the Jet Propulsion Laboratories of California Institute of Technology at Pasadena, where he received a B.S. and an M.S. Following graduation he did research for the Lockheed Aircraft Corp. for three years and then became physicist at the Mare Island Navy Yard.

Pol Duwez (p. 943). See JOURNAL OF METALS, September, 1949.

Donald L. Leman (p. 945) has been associated with the magnesium lab. at the Dow Chemical Co.,

D. L. Leman

Midland, Mich., since graduating from Carnegie Institute of Technology with a B.S. in Metallurgical

Continued on p. 895

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Authors In This Issue

Engineering. Around his home in Freeland, Mich., he finds good use for the gun and the rod.

John J. Casey (p. 945) has been Metallurgist at the Magnesium Laboratory of the Dow Chemical Co., Midland, Mich., for the past four years and for the same period

J. J. Casey

previous he was Captain in the Air Corps stationed at Wright Field Materials Laboratory. He is a native of Buffalo, and received a B.S. degree in Metallurgical Engineering from the University of Michigan.

Robert S. Busk (p. 945). See JOURNAL OF METALS, February, 1950.

Morris E. Fine (p. 951), a member of the technical staff of the Bell Telephone Labs at Murray Hill, N. J., was born in Jamestown, N. D. From the University of Minnesota

M. E. Fine

he received degrees of B. Met. Eng., M.S. and Ph.D., where he was also a Research Fellow and an instructor. From 1944 to 1946 he worked on the Atomic Bomb project at the Universty of Chicago and at Los Alamos. An AIME member, he has contributed to the Institute's Transactions. Classical music and tennis keep him occupied during some of his free hours at his home in Morristown, N. J.

R. P. Heuer (p. 921). See JOURNAL OF METALS, June, 1950.

M. A. Fay (p. 921). See JOURNAL OF METALS, June, 1950.

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New Products, Services and Information....

Products and services recently announced are described here. Also, new publications offered free by producers servicing the metalworking industry are listed.

For further information on any product or for your copies of the free publications, fill in the coupon below and send it to the *Journal of Metals*.

1) INGOT MOLD COATING: A new ingot mold, MEX, is claimed to combine the best features of an ideal coating with none of the undesirable characteristics. MEX, containing Mexican graphite, is safe, easy to use, gives off no fumes, and is not harmful to skin or clothing. It contains a hydrocarbon for "gas kick" in repelling metal splash. Stripping is easier because of the non-wetting, lubricating action of the graphite. MEX will stay in suspension for hours. It costs less than $\frac{3}{4}$¢ per ingot ton to use, and spray equipment is furnished free for testing with orders or 5 tons or more. *United States Graphite Co.*

2) ELECTRO DYNAMIC MICROMETER: The new Electro Dynamic Micrometer accurately measures dynamic or static displacement due to eccentricity, axial vibration, radial whip, bearing clearance, reciprocating movement, and radial expansion with acceleration. Direct reading from the micrometer head of the sensing unit makes calibration of electronic components unnecessary; and calibrations in divisions of 0.0001 in. are provided. The oscillograph will show a displacement vs. time curve on the screen. Measurements are made without physical contact between the sensing unit and the metal body. Sensitivity is equal to 1 pct of total displacement. *Electro Products Laboratories, Inc.*

3) DUST COLLECTOR: Large bulk, inflammable dusts, such as shavings, saw dust, chips, etc. can be collected by the new low cost "Dustbuster," which is 24 x 26 in. x $5\frac{3}{4}$ ft, weighing 240 lb, and costing $165. *Aget-Detroit Co.*

4) FIRE EXTINGUISHER: *The American-La-France Foamite Corp.* announces a new fire killer, Foamite Airfoam. It is a stable, cohesive, free flowing, protein-base foam extinguishing agent that blankets fire with thick insulation, cuts off air, and smothers the blaze, working equally well with fresh and salt water. Floating on surfaces of burning liquids, it smothers fire without harm to petroleum products or other flammable liquids.

5) MICROSCOPES: For laboratories there is available the new Series E research microscopes and accessories. All models have inclined binocular bodies that can be interchanged with graduated monocular draw tubes for photomicrography, measuring micro-projection, and other research applications. The draw tube is adjustable and graduated from 146 to 172 mm in tube length. *Bausch & Lomb Optical Co.*

6) CASTING CLEANER: Three or four pushes on a foot pedal to lift and position a casting in a vise simplifies casting cleaning with the new hydraulic vise manufactured by the *Bayless-Kerr Co.* A safety valve protects against overloading. Jaws can be closed without crushing or marring light castings or finished surfaces.

7) MAGNETIC SEPARATOR: *Eriez Mfg. Co.* offers a permanent magnet device for removing ferrous parts and contamination from electroplating tanks, alkali baths, acid baths, etc. Made of stainless steel it is temperature-proof, acid and alkali-proof, and operates like a carpet sweeper. The unit is light, easy to handle, and will not attach itself to the tank. Overall length 48 in.; widths $16\frac{1}{4}$ and $21\frac{1}{8}$ in.; and price $35.50 for the smaller size and $41.50 for the larger.

8) BAKING CORES: Model M-7200 Ther-Monic electronic core baking tunnel, with a baking cycle of only a few minutes and a capacity of 4 tons of cores per hr, has been developed by the *Induction Heating Corp.* It is capable of baking cores up to 60 in. wide with a maximum combined height of core and core plate of 20 in. Conveyor speed is adjustable from 0 to 6 ft per min. Green cores may be loaded in the core room directly to conveyor, eliminating racking and much handling of green cores.

9) RESISTANCE BOXES: A feature of the new ac and dc resistance measurement boxes manufactured by *Leeds & Northup Co.* is a new rotary switch having resistance of less than 0.002 ohm per decade and changing less than 0.0005 ohm per decade on accelerated life tests. They accommodate banana plugs, spade or spring clips, or bare wire of any size.

10) WELDING ELECTRODE: A new mild steel E6012 electrode, "Fleetweld 72" is introduced by the *Lincoln Electric Co.* for high speed single pass filet and lap welds in the flat or horizontal positions. Unusually high production speeds are claimed. Available at standard prices in 14 and 18 in. lengths and in various sizes.

11) VOLTAGE STANDARDS: Extreme stability is claimed for the new line of voltage standards developed by *Sorensen & Co., Inc.* All units are sealed and guaranteed to maintain rated output for six months, eliminating batteries, standard cells or the usual regulator-rectifier combinations.

12) TIN CONTENT INDICATOR: To determine the ratio of lead and tin content in solder, a new portable sensing reading indicator is offered by the *Wheelco Instruments Co.* that eliminates time consuming laboratory tests. Resistant to shock, heat, vibration and stray fields, its scale is calibrated in divisions from 0 to 7 pct, representing tin content of solder.

13) SPEED BRIDGE THERMOMETER: The new speed bridge thermometer permits following changing temperatures with moderate reading error, particularly on high speed units. It is encased in a $7\frac{3}{4}$ x 12 x 7 in.

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carrying case with a line cord and plug for connection to a 115 v, 60 cycle power line. *Paul G. Weiller.*

14) PYROMETER CONTROLLERS: *The Wheelco Instruments Co.* announces a new control system to their Capacitrol line of indicating pyrometer controllers. Designated as Model 252P, the "Capaciline"—Capacitrol combination offers a dependable low priced unit on heat treating, chemical, plastic, and other processing, where exceptionally close control is necessary.

15) FREIGHT CAR FLOORING: Developed by the *Armco Steel Corp.* is a new type of freight car flooring for box cars, gondolas, and flat cars. Hat shaped steel ribs, placed across the width of the car and welded to the center sill, stringers, and side sill angles, alternate with wood planks bolted to the rib flanges. A saving of $26.50 per year over a 25 year period is anticipated. It will not sag under concentrated loads and holds loads up to 10,000 lb.

Do You Have These Free Publications?

16) COLLOIDAL GRAPHITE: "Aquadag," "Prodag" and other "dag" dispersions for coating chills, molds, mold cavities, and patterns; for treating gates, risers, and runners; and for lubricating shoulder screws, base plates, and push pins, are described by formula with many helpful suggestions for application in a bulletin issued by the *Acheson Colloids Corp.*

17) ELECTRIC FURNACES: High temperature "unit-package" electric box and muffle furnaces for melting, sintering, heat treating, ignitions, etc. are described in Bulletins 315 and 515; and high temperature "unit package" electric tube furnaces for determination of carbon or sulphur by combustion and for experimental or production purposes are described in Bulletin 310. *Burrell.*

18) HEAT TREATING FURNACES: Bulletin HD 646 describes electric heat treating, carburizing, and other electric furnaces. Included are descriptions of how costs in heat treating, case hardening, and carburizing might be reduced. *Hevi Duty Electric Co.*

19) STAINLESS STEEL: "Stainless Steel for Heat Resistance" is the title of a 12-page booklet that discusses properties of stainless steel and outlines proper grades for parts subjected to heat. *Armco Steel Corp.*

20) ELECTRICAL EQUIPMENT MAINTENANCE: "Care of AC Rotating Equipment" is the title of a 24-page booklet telling of drying moist insulation, measuring insulation resistance to the bearing clearances and proper machine applications. *Allis Chalmers Mfg. Co.*

21) FATIGUE TESTER: Illustrated and described in a bulletin is Model SF-4 Sonntag fatigue machine. Static preload can be steplessly varied from 0 to 8000 lb, dynamic load capacity is 5000 lb, and capacity in one direction is 13,000 lb. The mechanism is seismically suspended on tension springs that absorb 99 pct of the vibratory forces. Its greatest field of usefulness is in the tension range. *Baldwin Locomotive Works.*

22) MECHANICAL TUBING: Size, gage, and length tolerances and physical properties of ERW carbon steel mechanical tubing, hot and cold rolled are contained in bulletin TB-333. *Babcock & Wilcox Tube Co.*

23) CLEANING MACHINES: A profusely illustrated catalogue of metal cleaning and finishing machinery is available. Many of the photos show "in operation" views, together with diagrammatic details. *Cincinnati Cleaning and Finishing Machinery Co.*

24) X-RAY SERVICE: A packaged X-ray service, complete with equipment, maintenance, repair parts, tubes and instruction—all covered by one monthly charge—is offered as the "Maxi-service" Plan. The monthly charge covers rental of equipment, instruction in its use, maintenance service, replacement parts, property taxes and interest costs—without investment. *General Electric X-Ray Corp.*

25) MALLEABLE ANNEALING: An illustrated bulletin describes new malleable annealing furnaces as well as the low hydrogen gas generator for controlled atmosphere malleable annealing. The furnace permits continuous operation; and the furnace chamber is 88 ft long, and is heated by 32 gas firing radiant tubes. *Holcroft & Co.*

26) OIL SEALS: Of importance to designers, engineers and maintenance men is a 16-page illustrated handbook of useful data on oil seals—where to use "Clipper" seals and how to install them. *Johns Manville.*

27) REFRACTORIES: Refractory products, together with application information and other useful reference data, are described in Bulletin No. 128A. It lists a five point maintenance service for longer furnace life. *Laclede-Christy Co.*

28) LABORATORY EQUIPMENT: Of interest to scientists and engineers is a new quarterly on scientific apparatus, including Christian-Becker balances, battery chargers, filter pumps, funnels, furnaces, high frequency coils, hydro-aspirators, panfocal illuminators, potentiometers, projectors, pumps, titrators, etc. It gives illustrated and descriptive information concerning their use and prices. *E. H. Sargent & Co.*

29) GAS METERS: A bulletin describes the "Flo-Scope" for indicating flow rates of air or gases during confined travel. The instrument is used primarily for combustion equipment, but can be used where air or non-corrosive gases are transferred from one place to another through piping. *Selas Corp. of America.*

30) LUBRICATION: In an illustrated booklet are listed "11 Ways to Cut Production Costs" of industrial lubrication through simplified methods—from barrel to bearing. *Stewart-Warner Corp.*

31) PHOSPHATE COATING: A comprehensive phosphate coating chemical selection chart of value in specifying requirements is offered. Government specifications are listed. *American Chemical Paint Co.*

32) SPECTROCHEMISTRY: Scientists and spectrochemists will be interested in Bulletin 33 on "Infra-red Recording Spectrophotometer" and Bulletin 1 on "Better Analysis" issued by *Baird Associates, Inc.* Through the use of infra-red analysis, economies are reported in the petroleum and organic chemical industries. Special techniques make it possible to apply the method to the study of inorganic molecules.

33) TEMPERATURE AND PRESSURE INSTRUMENTS: From the *Fischer & Porter Co.* come new measuring, exhibiting, and controlling temperature and pressure instruments. Temperature instruments, "Rathotherm," have thermal systems filled with liquid, vapor-liquid, or gas covering ranges between 125 F and plus 1000 F. Pressure instruments, "Ratogage," have bellows, multiple-diaphragm, slack-diaphragm, or helical pressure-measuring elements covering ranges between 30 in. of mercury vacuum and 10,000 psi.

Engineering Societies Personnel Service

THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc., operating in co-operation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., **New York 18**; 100 Farnsworth Ave., **Detroit**; 57 Post St., **San Francisco**; 84 E. Randolph St., **Chicago 1**. Applicants should address all mail to the proper key numbers in care of the New York Office and include 6¢ in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter or $12 a year.

McKinless Named Detroit Manager

The Engineering Societies Personnel Service, Inc., announced the appointment of Lt. Col. Frank McKinless as manager of its Detroit office.

Col. McKinless, a graduate of the Colorado School of Mines, has had 25 years of experience in the design, production, sales and management fields. He served with the Marine Corps in both world wars and was in charge of Personnel Procurement for the Marines in the New York District during World War II.

Positions Open

Mechanical or Metallurgical Engineer, under 35, graduate, with experience in mechanical development and design, to carry out outlined phases of design projects and assist in laboratory development of new equipment and processes in metal fabrication field. Must have technical design experience in appropriate field, i.e., machine design, welding, fluid flow of gas combustion. Salary, $3300-$5100 a year. Location, northern New Jersey. Y3689.

Metallurgist, 25-35, with experience in metallographic laboratory, to perform varied analyses, using spectrographic methods, quantometer and other metallurgical and chemical equipment. Salary, $3900-$4500 a year. Location, State of Washington. Y3654-R6512.

Machine Designers with at least five years' experience on the design of steel mill or product machinery, to design and lay out tube mill flat rolled, processing and general steel mill equipment. Salary open. Location, Ohio. Y3643C.

Assistant Shop Superintendent who has had experience in a steel fabricating shop, for a shop fabricating structural steel, miscellaneous and ornamental iron and resistance welded grating. Location, Tennessee. Y3541.

Steel Buyer, not over 45, preferably mechanical graduate, with at least 10 years' experience in the purchase of all types of process steel. Salary, $10,000 a year. Location, New York, N. Y. Y3531.

Sales Engineer with several years' experience in selling centrifugal process pumps to oil refineries. Salary open, plus commission. Headquarters, New York. Y3059.

Steel Metallurgist, preferred age 35, graduate; metallurgist with solid experience and proved ability in industrial research, for responsible position steel section of research laboratory of large corporation. Location, northern New Jersey. Y2854.

Sales Engineer, 30 to 40, with at least three years' experience in the sale of stainless steel castings in the East, to solicit production orders for western foundry. Considerable traveling. Salary, $3000 a year. Headquarters, New York, N. Y. Y3414.

Metallurgical Engineer, June Graduate, University of Pennsylvania, 24, veteran, married, one child. Interested in position in physical metallurgy that will afford opportunity to gain experience and all-around knowledge. Available for work Aug. 7, following six weeks' course at Aberdeen Proving Grounds to receive reserve commission in Ordnance. Location immaterial. M-549.

Metallurgist, M.S. from M. I. T. February, 1950, age 21. Desires position in physical metallurgy research or development. Location immaterial. M-551.

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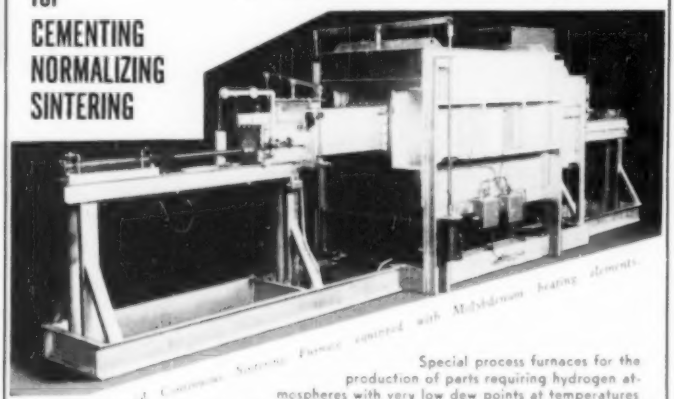

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Men Available

Metallurgical Engineer, B.S., Carnegie Tech, 1950, age 31, married, veteran. Development, production and control are major interests. Have had four years foundry control and four years part-time development work. Will consider any location but wish to settle in western Pennsylvania. M-552.

Metallurgist, B.Ch. E. (Metallurgy option) July, 1950, desires position metallurgy development or foundry departments. Veteran, 25, single. Knowledge of statistical quality control. Prefer eastern United States. M-553.

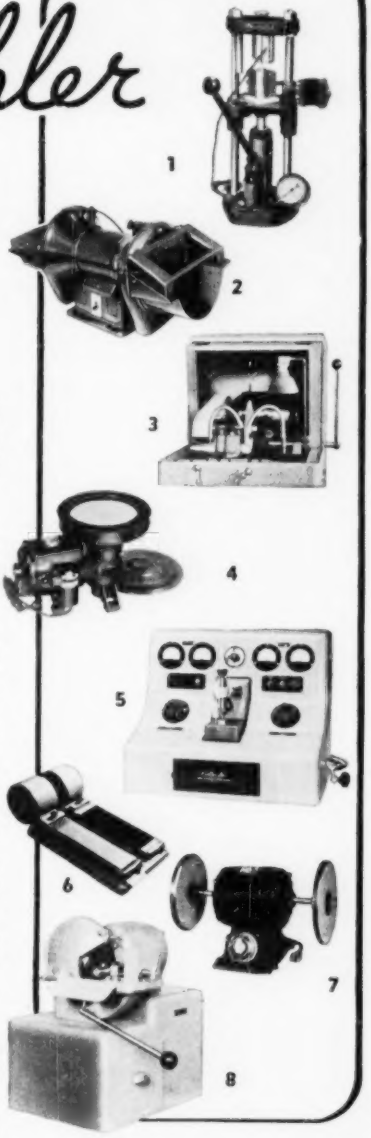
Metallurgical Sales Development Engineer, 32 to 38, graduate, with experience in the processing and application of alloy steel. Location, Illinois. Y3737.

Engineers. (a) Tool Room Foreman, 35 to 50, experienced with tools, dies, progressive dies and eyelet machine tools that are used in the manufacture of brass fabricated items of small and medium design. Must be able to produce the tools on schedules and at estimated costs. Salary, $4000 to $4300 a year. (b) Production Supervisor, 35 to 50, experienced in the production of metal fabricated parts of small and medium design. Experience must be broad with all types of brass, eyelet machines and other metal working machinery. Must be able to produce parts at the estimated cost. Salary, $3600 to $3900 a year. (c) Mechanical Engineer, 35 to 50, mechanically trained in metallurgy and engineering. Must be able to cover the estimating, the designing and processing of brass fabricated parts. Work will involve brass fabricating of small and medium parts and he must have an intimate knowledge of tools, dies, progressive dies and eyelet machine tools. Salary open. Location, Connecticut. Y3363.

Instructor for Metallurgy Dept. at eastern university. Minimum salary, $3000 a year. Opportunities for graduate study and research. Distinguished undergraduate record and stimulating personality necessary. Y3281.

Buehler

Offers a Complete Line of Equipment for the . . . METALLURGICAL LABORATORY



Buehler specimen preparation equipment is designed especially for the metallurgist, and is built with a high degree of precision and accuracy for the fast production of the finest quality of metallurgical specimens.

1. No. 1315 Press for the rapid moulding of specimen mounts, either bakelite or transparent plastic. Heating element can be raised and cooling blocks swung into position without releasing pressure on the mold.

2. No. 1211 Wet power grinder with ¾" hp. ball bearing motor totally enclosed. Has two 12" wheels mounted on metal plates for coarse and medium grinding.

3. No. 1000 Cut-off machine is a heavy duty cutter for stock up to 3½". Powered with a 3 hp. totally enclosed motor with cut-off wheel, 12" x 5/32" x 1-1/4".

4. 1505-2AB Low Speed Polisher complete with 8" balanced bronze polishing disc. Mounted to ½ hp. ball bearing two speed motor, with right angle gear reduction for 161 and 246 R.P.M. spindle speeds.

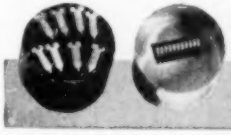
5. No. 1700 New Buehler-Waisman Electro Polisher produces scratch-free specimens in a fraction of the time usually required for polishing. Speed with dependable results is obtained with both ferrous and non-ferrous samples. Simple to operate—does not require an expert technician to produce good specimens.

6. No. 1410 Hand Grinder conveniently arranged for two stage grinding with medium and fine emery paper on twin grinding surfaces. A reserve supply of 150 ft. of abrasive paper is contained in rolls and can be quickly drawn into position for use.

7. No. 1400 Emery paper disc grinder. Four grades of abrasive paper are provided for grinding on the four sides of discs, 8" in diameter. Motor 1/3 hp. with two speeds, 575 and 1150 R.P.M.

8. No. 1015 Cut-off machine for table mounting with separate unit recirculating cooling system No. 1016. Motor 1 hp. with capacity for cutting 1" stock.

The Buehler Line of Specimen Preparation Equipment includes . . . Cut-off Machines • Specimen Mount Presses • Power Grinders • Emery Paper Grinders • Hand Grinders • Belt Surfacers • Mechanical and Electro Polishers • Polishing Cloths • Polishing Abrasives.



Buehler Ltd.
A PARTNERSHIP
METALLURGICAL APPARATUS
165 WEST WACKER DRIVE, CHICAGO 1, ILLINOIS

when you need "spillage" protection

it's the

LINDBERG

LABORATORY HOT PLATE

The Lindberg Hot Plates have the built-in spillage protection that the baby kissin' politician wishes he had.

Maximum protection from corrosion, discoloration and hazards caused by spillage of liquids and chemicals onto the heating element is a built-in feature of the specially "metalized" top plate. The special ¼" metal top plate resists growth and warpage . . . rounded edges and apron protect underlying elements . . .

Coiled nickel-chromium elements heat the entire top uniformly from 130° to the continuous operating peak of 950° F. (54 to 510° C.) . . . **simple, step' ss temperature control to any degree of heat within the working limits is supplied by the exclusive Lindberg Input Control.**

All parts of the unit are protected by heavy insulation and sheet steel. All instruments and controls are built-in . . . ready for one connection to the power source. Smooth button supports prevent the unit from disfiguring its supporting surface. Units are carefully packed and individually shipped.

Ask your laboratory equipment dealer for full details, or write Lindberg Engineering Company, 2466 West Hubbard Street, Chicago 12, Illinois. *Ask for Bulletin 962.*

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LABORATORY HEATING APPARATUS

Research Position Open

PHYSICIST, Ph.D. or man suitably qualified to carry out investigations involving X-ray diffraction as applied to metals. Excellent opportunity for man with good theoretical background and experimental ability. Some familiarity with structure analysis desirable. Send complete resumé to:

Personnel
SYLVANIA ELECTRIC PRODUCTS, INC.
40-22 Lawrence St., Flushing, N. Y.

PLANT SUPERINTENDENT—Graduate. 15 years' experience smelting and refining of nonferrous residues with one company. Advanced from Control Chemist through production departments. Age 36.
Box K-10—JOURNAL OF METALS

NON-FERROUS FOUNDRY CONSULTANT. Graduate engineer, preferably metallurgical, with brass and aluminum sand foundry experience to act as field service representative for producer of non-ferrous ingot. Please give complete details in first letter.
Box K-11—JOURNALS OF METALS

WANTED—METALLURGIST for melting department specializing in the production of stainless, high-temperature alloys, and tool steels. Preference given to men having several years' experience with arc furnace production of above materials.
Box K-12—JOURNAL OF METALS

The look that keeps telephone costs DOWN

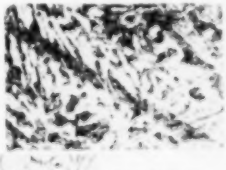
Examining specimen on metallographic microscope at Bell Telephone Laboratories.

Through his microscope this Bell metallurgist examines a bit of material which is proposed for telephone use. From what he sees of grain structure, he gains insight into performance not provided by spectrum or chemical analysis. He learns how to make telephone parts stand up longer, so that telephone costs can be kept as low as possible.

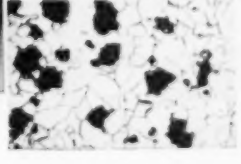
The items which come under scrutiny are many and varied, ranging from manhole covers to hair thin wires for coils, from linemen's safety buckles to the precious metal on relay contacts.

In joints and connections—soldered or welded, brazed or riveted—photomicrographs reveal flaws which would escape ordinary tests. They show if a batch of steel has the right structure to stand up in service; why a guy wire let go in a high wind or a filament snapped in a vacuum tube; how to make switchboard plugs last longer.

In their exploration of micro-structure, Bell Telephone Laboratories scientists have contributed importantly to the metallographic art. You enjoy the benefits of their thoroughgoing testing and checking in the value and reliability of your telephone system, and the low cost of its service.



Photomicrograph of white cast iron which is hard and brittle.



Same iron rendered malleable by heat treatment. Shows spots of nodular carbon.

BELL TELEPHONE LABORATORIES

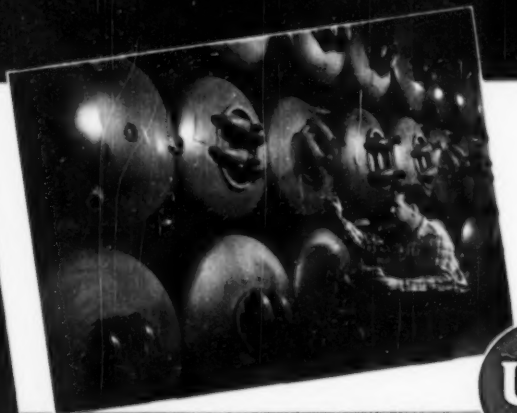
WORKING CONTINUALLY TO KEEP YOUR TELEPHONE SERVICE BIG IN VALUE AND LOW IN COST

Sometimes it costs less to use Steel that costs more!

Here, U·S·S COR-TEN used cuts weight 18%

The bigger the tank the bigger the saving

In the 42" x 10' Stonesteel tanks under construction above, the use of COR-TEN reduces weight 553 lb., saves $5.00 on material cost. When these lighter COR-TEN tanks were shipped to a housing development in Norfolk, Va., freight charges were $9.84 less, bringing the total savings per tank to $14.84.



USS

in place of carbon steel

cuts material cost 10.8%

cuts shipping cost 16%

During the past 12 years, U·S·S Cor-Ten—the pioneer high strength steel—has earned a world-wide reputation for reducing costs by reducing weight in freight cars, buses, trucks and other mobile equipment. That's exactly what Cor-Ten was developed for, so we were not surprised.

But here is the story of a money-saving application, far outside the transportation field, that aptly illustrates how stationary equipment of many kinds can be built advantageously of U·S·S Cor-Ten in place of carbon steel—not only to improve the product but to reduce its cost.

SEVERAL years ago the Cemline Corporation of Cheswick, Pa., developed a hot water storage tank designed to prolong life even in those areas where water supplies are unusually corrosive. A special hydraulic cement lining that prevents corrosion by eliminating any corrosive water-to-metal contact did the trick. But in solving the corrosion problem the cement lining created another. Its substantial weight when added to the weight of the heavy carbon steel shell resulted in a unit that was unwieldy to handle and difficult and costly to install.

A lighter tank was definitely called for. This need was emphasized with every increase in freight rates, and as more and more tanks were shipped to distant markets. The question was, how to reduce weight and still meet high strength requirements. Cemline engineers found the answer in U·S·S Cor-Ten.

Due to the protective lining, interior corrosion could be disregarded, so they were able to take full advantage of U·S·S Cor-Ten's high yield point (50,000 psi.) and to use it in gages 40% lighter than the carbon steel gages previously required. This 40% reduction in cylinder weight reduced the total tank weight 18%.

These weight savings resulted in cost savings all along the line. Cost of the steel per cylinder was 10.8% less (because the weight saved more than offsets Cor-Ten's slightly higher cost). The lighter tanks were handled with less trouble and less expense. And, freight charges on every shipment—on steel from the mill, on the tanks to the customer—were reduced almost 16%.

To show what this means in actual dollars and cents savings, take the case of the 45-gallon Stonesteel tank (shown at right) produced by the thousands for residential use. Replacing the carbon steel shell, .138" thick, with U·S·S Cor-Ten .0828" thick, reduced weight 42 lb., cut steel cost 35 cents. When these tanks were shipped to Richmond, Va., freight charges were 72 cents less for the lighter tanks, making a total saving per tank of $1.07.*

"U·S·S Cor-Ten," says the President of Cemline Corporation, "does more than reduce our costs. Because of its stiffness it forms more smoothly on our bending rolls, and fluting difficulties formerly experienced have disappeared. In welding, too, Cor-Ten behaves better than straight carbon steel. It does not seem to burn away so readily under the arc and thus makes welding easier and faster. We know our customers have less trouble and less expense handling these lighter Cor-Ten tanks. And because Cor-Ten has from 4 to 6 times greater atmospheric corrosion resistance we have every reason to believe that Stonesteel tanks made of U·S·S Cor-Ten are much less likely to rust when exposed to external condensation, when leaky fittings drip or when the enameled surface is damaged in shipping or installation. That's why, for all our tanks, except where codes require flange steel construction, we've standardized on U·S·S Cor-Ten."

AMERICAN STEEL & WIRE COMPANY, GENERAL OFFICES: CLEVELAND, OHIO
CARNEGIE-ILLINOIS STEEL CORPORATION, PITTSBURGH & CHICAGO
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U·S·S HIGH STRENGTH STEELS

U·S·S COR-TEN · U·S·S MAN-TEN · U·S·S MANGANESE-NICKEL-COPPER

United States Steel Corporation Subsidiaries
Room 2088 Carnegie Building, Pittsburgh 30, Pa.

- ☐ Please send me a copy of booklet showing how U·S·S Cor-Ten saves money in building Stonesteel tanks.
- ☐ Please have a High Strength Steel representative call on me.

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UNITED STATES STEEL

Advertisement

ELECTROMET *Data Sheet*

A Digest of the Production, Properties, and Uses of Steels and Other Metals

Published by Electro Metallurgical Division, Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. • In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario

VANADIUM...the metal that accentuates the effects of other alloying elements

Vanadium is usually added to steel or iron along with other alloying metals, such as manganese, tungsten, nickel, or chromium. It enhances the effect of these other alloys and helps to improve the physical properties of the metal. Generally it is used in quantities of less than 0.50 per cent, but even in these small amounts it is responsible for many marked improvements in the quality of iron and steel.

One of the most notable functions of vanadium is its effect in improving the dynamic properties of steel, such as fatigue and impact resistance. It also gives an inherently fine grain size to both steel and iron.

In high-speed tools, vanadium contributes wear resistance and red hardness. It is also an important alloy in many types of permanent magnet steels. These and many other types of special-purpose steels contain more than 0.50 per cent vanadium to enhance certain properties.

Dynamic Strength for Steels

The principal effect of vanadium in engineering steels is that of refining grain size. It is usually added in amounts of 0.10 to 0.25 per cent.

Fig. 1. Steels in which vanadium is an alloy have outstanding dynamic strength. That is why they are frequently used in such heavy-duty service as springs and axles in diesel locomotive trucks.

In the lower carbon ranges, vanadium steels are especially suited for carburizing and are used for such applications as hand tools, bearings, and pistons. Vanadium-bearing steels can also be nitrided effectively.

Vanadium contributes fatigue and impact resistance and also strength and ductility to spring steels. The famous chromium-vanadium (SAE 6100 series) and manganese-vanadium spring steels are outstanding examples of this use. Besides being used as springs, these steels are frequently used for axles, shafts, and other highly stressed moving engine parts.

Red Hardness in Tools

Practically all fine tool steels contain vanadium. In high-speed steels, vanadium content usually ranges from about 0.50 to 2.50 per cent, although higher percentages are sometimes used. Other alloy tool steels usually contain from 0.20 to 1.00 per cent vanadium.

Vanadium is a strong carbide-former and forms very hard and stable carbides. These vanadium-carbides are probably the main reason for the excellent wear resistance and edge-holding properties of vanadium tool steels. The persistence of the vanadium-carbides is largely responsible for the cutting qualities at red hardness of high-speed tool steels.

Adds Strength to Cast Iron

In amounts of 0.10 to 0.15 per cent, vanadium increases the strength of cast iron from 10 to 25 per cent, and adds a considerable amount of toughness. Cast iron containing vanadium is especially valuable in such applications as steam locomotive cylinders, valve and piston bushings, piston rings, and similar parts. In steam engines and diesel motors, vanadium cast iron cylinders greatly outlast those of ordinary cast iron. Chromium-vanadium cast iron rolls, containing up to 2 per cent chromium, have been used successfully in steel mills for a great many years.

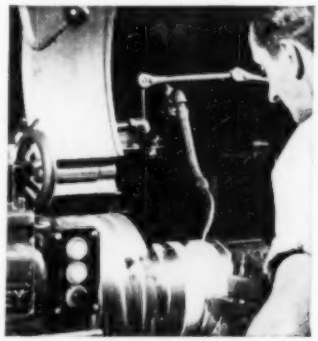


Fig. 2. Nearly all fine tool steels contain vanadium. It promotes fine grain size, high wear resistance, and greater control of hardenability. Vanadium also contributes to the red hardness of high-speed tool steels.

Cast iron in which vanadium is the sole alloying element is used primarily in applications where temperatures are moderately high and in heavy sections requiring uniform hardness without brittleness.

ELECTROMET Vanadium Alloys

ELECTROMET produces three grades of ferrovanadium in various sizes for the production of vanadium-bearing steels and irons. Each grade has a definite range of carbon and silicon contents and is especially adapted to assure the best results in the different requirements of iron and steelmaking.

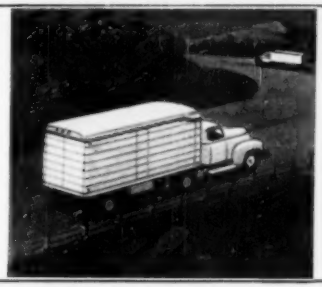
Write for a copy of the booklet, "ELECTROMET Ferro-Alloys and Metals." It contains many useful facts about the use of ferrovanadium. The booklet also describes over 50 other alloys and alloying metals produced by ELECTROMET.

The term "Electromet" is a registered trademark of Union Carbide and Carbon Corporation.

MAGNESIUM MAKES MANY PRODUCTS BETTER

Example
TRAILER FLOORING

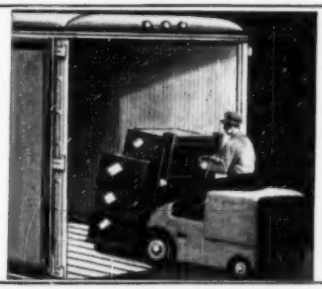
Light!



To lighten his trailers and make them more profitable to operate and easier to sell, a leading trailer manufacturer designed a magnesium floor. The new floor was 44% lighter —724 lb. was added to the cargo capacity of a 35′ van trailer.

724 lb. Lighter than Previous Floor

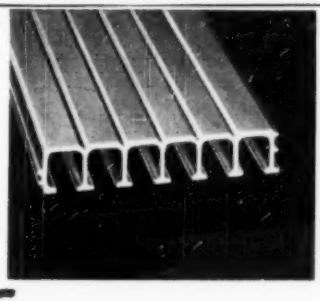
Strong!



In addition to being 724 lb. lighter than the older floor, the new magnesium floor is much stronger and can stand more abuse. Here again, sound design that takes full advantage of the very favorable strength and weight characteristics of magnesium results in a better product.

Even Stronger than Floor it Replaced

made with



The versatile extrusion process provided the right answer to this problem. Trailer-length magnesium "planks" with the necessary multi-ribbed section were extruded at surprisingly low cost. No further forming or shaping was required. And the close tolerances obtained cut assembly costs.

Dow Magnesium!

THE WORLD'S LIGHTEST STRUCTURAL METAL

A lighter trailer, a stronger trailer, a trailer that is more profitable to operate —that's what magnesium's extra lightness means to the trucker!

Magnesium lightness means better products in many other fields as well. Business machines, portable tools, materials handling equipment, reciprocating machinery, and truck bodies are just a few of the products that have been improved with light, strong magnesium. There are many others.

If you are redesigning your old product, or developing a new one, it will pay you to investigate magnesium. For more complete information about this economical, lightweight metal, write Dept. MG-31 in Midland.

Magnesium Division • THE DOW CHEMICAL COMPANY • MIDLAND, MICHIGAN

New York • Boston • Philadelphia • Washington • Atlanta • Cleveland • Detroit • Chicago • St. Louis • Houston • San Francisco • Los Angeles • Seattle • Dow Chemical of Canada, Limited, Toronto, Canada

Put CUPRO-NICKEL in to keep CORROSION out

Aship and ashore, vital metal parts of many types of equipment often operate under conditions exposing them to salt water corrosion. And that's where cupro-nickel alloys prove their worth . . .

In fact, during World War II, all available 70-30 copper-nickel condenser tubes were reserved exclusively for Naval vessels and tankers.

And the reason? Because thin walls of this strong, tough alloy resist corrosive and erosive attacks from salt water. This resistance extends to sea water containing entangled air bubbles, which passes through condenser tubes at high velocities, and to polluted, silt-laden waters of harbors and estuaries.

In addition, the 70-30 alloy combines outstanding resistance to pitting and stress corrosion cracking, plus maximum resistance to dezincification, together with the ability to withstand a wide variety of corrosive agents.

The International Nickel Company, Inc.
Dept. JM, 67 Wall St., New York 5, N. Y.

Gentlemen:

Please send me additional information about cupro-nickel alloys.

Name _____ *Title* _____

Company _____

Address _____

City _____ *State* _____

APPLICATIONS

Ocean-going ships equipped with cupro-nickel condenser tubes and piping can travel hundreds of thousands of miles and many years longer without layovers for tube replacement . . . a particularly important advantage for merchant vessels.

But that is only one example. Cupro-nickel alloys have established outstanding service records in applications ashore as well as at sea. They serve in sugar mills, oil refineries and power plants . . . in vital parts of feed water heaters, condensers, evaporators and other heat exchangers . . . in oil coolers, stills, water boxes, piping, tanks, and other equipment.

Cupro-nickel alloys eliminate those hidden taxes on profits represented by maintenance, replacement expense, loss of heat transfer capacity and interruptions of operation resulting from corrosion.

TYPES AVAILABLE

Cupro-nickel alloys are available in many types containing various percentages of nickel. The most widely used for condenser tubes and marine shore station applications is composed of 70% copper and 30% nickel. Another which is gaining wide acceptance is the new iron modified 90-10 cupro-nickel.

Cupro-nickel is available as tubing, rod, strip, wire and sheet, and also in cast form.

We shall be glad to give you additional information about these versatile cupro-nickel alloys and help you select the one best suited to your requirements. Write us today.

INCO

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

* A 12-year agreement has been made between the Armco International Steel Corp. and the Italian Finisder Steel Corp. for a vast modernization program for Italian industry. First project will be a $100,000,000 continuous strip mill in Genoa.

* A plant reequipment program for Ford Motor Co., Ltd., of England, will result in purchases of certain specialized machine tools in the United States. The bulk of purchases for the program will be made in the United Kingdom, but equipment not available will be imported from North America. Dollars have been made available for these essential purchases by drawing the necessary sum from the United Kingdom ERP allocation by arrangement with ECA.

* A pressure-type bonding furnace, for bonding composite metal packages, consists of two hydraulic presses incorporated in a reducing atmosphere bonding furnace. One press is in the high heat zone and the other in the cooling zone. These presses assure a tight, uniform bond between gold and base metal packages, preparatory to rolling (p. 916).

* Nickel-aluminum-bronze alloy, marketed under the trade name "Nikalium" is being used in the manufacture of ship propellors by a British firm. Some 25 propellers have been made of this alloy, none yet above a 3¼-ton size. Though more expensive and difficult to produce than manganese bronze, the alloy is reported considerably stronger.

* A steel rolling mill, to be known as Israel Rolling Mills, Ltd. is to be built in the industrial zone of Haifa Bay in Israel. H. A. Brassert & Co. are consultants on the project. Three merchant mills are being installed now, and 6-in. billets will be imported. Later, an electric furnace will be added. (p. 913).

* The proposed expansion of the Royal Netherlands blast furnaces and steelworks at Ymuiden, for which ECA granted about $23 million has advanced a step by the Dutch Government's entering a bill in Parliament to provide state aid. Plate capacity will be raised from 140,000 to 205,000 tons; and a tinplate plant and a new company for making hot rolled strip are proposed.

* A new type of stress and strain recorder that operates in conjunction with a Baldwin-Southwark 100,000-lb testing machine for tensile, compression, shear, and bending is in use at the Naval Engineering Experiment Station, Annapolis, Md. A new-type microformer in the strain amplifying mechanism replaces the old micrometer and lever system, which depended on the integrity of electrical contact.

* A military reference listing of scientists and engineers with names, background and experience of the nation's best scientific minds has been compiled. Originally a project of the Office of Naval Research, the source files will be maintained by the National Security Resources Board as a roster of talent available in an emergency.

* Modernizing an ancient art: Hunting arrows are being made with an aluminum shaft and die cast magnesium tips. Better balance, greater range and improved accuracy are claimed.

The *Drift of Things* . . . . . as followed by *Edward H. Robie*

CONGRESSIONAL hearings on a proposal to increase the duty on imported crude petroleum from half a cent a gallon to two cents a gallon, and on other matters of interest to various groups in the mineral industry, have brought all the old familiar arguments about the benefits and evils of tariff protection. As to the oil imports, the small "independent" oil producers and the coal producers are the chief protagonists for increasing the duty. They affirm that imported oil is making cut-throat competition which is driving oil and coal-mining companies out of business. Thousands of coal miners are jobless, the health of their children affected, and "even the public schools are imperiled." Also, the security of the country is threatened, for the supply lines of the imported oil would likely be cut in case of war, and it would take a long time to train miners and get domestic dormant mines back into operation. Much the same arguments, plus the complaint that foreign products afford unfair competition because of low labor costs through the use of slave or peon labor, are offered in arguments for increasing the tariffs on many other things.

On the other side of the fence are those that feel that John L. Lewis, by increasing the cost of mining coal and by strikes which have often made coal impossible to get at any price, has hurt the sale of coal much more than has imported oil. The suggestion has been made that the oil industry should send Mr. Lewis a bouquet of orchids every day.

Willard Thorp, Assistant Secretary of State, in opposing the proposed increased tariff, maintained that coal has lost ground to oil and gas for over thirty years and that the influx of foreign oil—now slightly under a million barrels a day—has had limited, if any, force on this trend. He asserted that oil is a vital part of the country's trade program; it is one of the ways that foreign countries pay for American exports. Security in case of war would be seriously threatened, too, for without an American outlet, foreign oil producers would be weakened, yet we would need their aid.

Neither did Mr. Thorp think that imported oil was harming the domestic oil industry to any extent to worry about, in view of the fact that new records were made in drilling last year.

The current discussion is part of the age-long controversy before Congress as to tariffs, subsidies, and price supports. On one side is the relatively small but insistent group of domestic producers whose welfare is hurt a great deal by free markets and absence of adequate tariff protection. Their investments and jobs may truly be wiped out, and the communities they support may become ghost towns. Protection is a vital matter to them. On the other side are the rest of the citizens of the country, enormously greater in number but comparatively disinterested because a few cents more or less that they pay for a few commodities does not affect them individually to any considerable extent. Only occasionally, such as when the Government buys up potatoes to keep the price up and then wastes them, does any considerable number of the common people protest.

Congress, being made up of all kinds of people, from those who place the business interests of large groups of their constituents first to those who are primarily interested in what is good for the country, or even the world, as a whole, usually winds up by adopting a middle ground.

In recent years there has been more of a tendency in the United States to break away from a local prosperity or nationalistic economy to the view that what is best for the country as a whole should be adopted. Further, that what is best for the world as a whole may well be best for the United States. This on the theory that peace, generally regarded as a sine qua non for the happiness of the country, is best assured by freedom of trade and higher standards of living in all countries. One of the leading spokesmen for this point of view is Sumner H. Slichter, Harvard business economist, whose lead article in the June Atlantic, "Our Best Defense", has aroused great interest.

Dr. Slichter points out some of the economic problems that the country must face in the next decade, and how the cold war with Soviet Russia can be handled. The two most important economic adjustments that must occur, he says, are a return of the prices of farm products to a long-term basis of demand and supply, and more equable conditions in our foreign trade. Three major trends must be halted, he believes: the rapid rise in government expenditures, the rapid spread of government intervention in business, and the drop in the influence of business men in the community.

Those who are against removal of tariff barriers, or favor increasing them, or who favor artificial prices to support domestic industries, will find little support in the Slichter article. For instance: "Substantial increases in imports of oil, iron ore, copper, lumber, and many foodstuffs would be in the national interest." "I do not assert that all of these regulations of the government are bad—though a few of them, such as the buying of silver, are completely bad, and others, such as the support of prices of farm products, are badly designed." "The discussion of the several problems . . . has indicated again and again the importance of two things: great increases in production and a large rise in imports."

New Oil Bonanza

If one turns to an ordinary atlas and tries to spot a certain county in Texas without the aid of an index he will find the job rather time-consuming for the Lone Star State has 264 such subdivisions, almost 100 more than the next most "countified" state of Georgia. However, in the western part of Texas the map is not too much cluttered up with towns and railroads and other evidences of civilization, so it is not too difficult to find Scurry County. In fact, its county seat, Snyder, stands out as more of a town than its 1940 population of 3815 would indicate. Lubbock, 80 miles to the northwest, was until a year and a half ago, much better known, but not now, at least among oil men. For Snyder is the center of a new boom, a new oil field that may rival the famous East Texas field. Its population has jumped to 30,000. Living quarters and public utilities are being hastily constructed and some 4000 trailers offer temporary homes.

No one knows how much oil there is underground but there are now some 700 wells producing from a reef formation 6000-7000 ft below the surface. Intelligent guesses indicate perhaps a billion and a half barrels of oil, more oil than was found in the first two years of East Texas, and more than has ever been found in Oklahoma, the fourth largest producing state in the Union. The field seems to be crescent-shaped, some 33 miles long at present, from its northeast extremity in Kent County, across Scurry County, to its southwestern end in Borden County.

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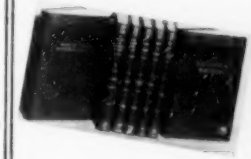
* Volume Number in Bold Face

Price to members of the AIME and to public libraries is subject to 30 per cent discount. No limit to number of copies members may order. Price to book dealers is subject to 20 per cent discount. An additional charge of 50¢ is made for each book mailed outside of the United States.



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aime NEWS

Increase in Quality Technical Papers Results in an Embarrassment of Riches

Either a greater amount of interesting work has been going on in the field of the AIME which inspires writers to record it for publication, or the various Divisional papers and programs committees have been much more active in soliciting such material. In any case, the Institute has been embarrassed by a superfluity of riches in the form of good technical papers, but unfortunately not also in the form of money. Last year 475 technical papers were submitted for Transactions publication, compared with 350 in 1948 and an average of 304 in the preceding five years. Papers accepted for publication last year totaled 282, compared with 209 in 1948 and an average of 216 in the preceding five years. Every year there is some carry-over of papers on which action has not been taken, and with the recent influx of papers, the number carried over naturally also increased, being 238 at the end of last December, compared with 165 a year before, and an average for the preceding five years of 96.

The publication problem that has faced the Institute so far in 1950 thus becomes evident. In 1949, and in the years immediately preceding, the Directors decided to incur substantial deficits rather than to decline good papers for publication. For 1950, on the other hand, with increased income from dues, it was felt that the budget should be balanced and that publication costs should not exceed available income. In the closing months of 1949, when the crest of a wave of incoming papers was reached owing to the Annual Meeting program, a substantial increase in advertising income for the three journals for 1950 was envisaged. Therefore, larger issues of the journals were planned for the first quarter than were later justified.

So far in 1950—that is, for the first six months—143 technical papers, totaling 2145 6 x 9-in. pages, have been published in the three journals, compared with 228 papers, totaling 3343 pages, for the entire year 1949. (The number of pages in 1950 and 1949 has been multiplied by 1.9 to make the data comparable to that for earlier years when the page size was 6 x 9 in., in the accompanying table.)

In brief, many more papers are available for publication in the last half of 1950 than can be published with the available funds. A restriction in the number to be published, or in the total number of pages they occupy, is therefore in order. Auxiliary publication committees are being urged: (1) To limit acceptances of Transactions material strictly to Grade A papers. (2) To urge maximum condensation of papers. (3) To advise Institute headquarters which papers can be postponed for publication in 1951 and which should be published promptly.

Papers are ordinarily written for two purposes: (1) To present at meetings. (2) For publication. Most of those on the technical programs for technical sessions of the Institute are prepared with the idea of publication as well as presentation; practically none are prepared for publication only. A paper is ordinarily condensed considerably when presented orally. It is entirely possible, also, to limit publication to a concise statement of facts, implications, and conclusions. Supporting data, or a more complete paper, can be made available through microfilm, through deposition in central libraries, by direct contact with the author, or by private publication or distribution.

The accompanying table compares the major professional interests of AIME members with the number of pages of Transactions papers that have been published in recent years on subjects of principal interest to them. Apparent illogicalities can be immediately noted. No exact or even approximate agreement between the percentage of AIME members in a certain professional group and the number of papers directed to the specific interests of that group should be expected. The main reason for lack of what might be expected to be a reasonable proportionality is a relatively greater amount of research, and other types of work that lead to papers, in some fields of endeavor than in others. This is conspicuously true for the Institute of Metals Division and its papers on physical metallurgy. The Minerals Beneficiation Division has also recently had more than its usual number of research-type papers to

Pages of Transactions Papers

(Major Divisional interest of membership, as indicated by cards returned to AIME headquarters, is given for comparison. Pages of Transactions material published in 1949 and 1950 have been multiplied by 1.9 to make the data comparable with earlier years when the page size was 6 x 9 in.)

Name of Division	Pct. of AIME Membership	First 6 Months 1950	1949	1948	Average 1943-1947
Mining, Geology & Geophysics	27.9	162	218	316	239
(Mining Subdivision)		(95)	(190)	(177)	(165)
(Geology Subdivision)		(59)	(0)	(124)	(86)
(Geophysics Subdivision)		(8)	(28)	(15)	(47)
Minerals Beneficiation	7.2	175	97	190	194
Coal	8.6	162	347	324	151
Industrial Minerals	3.6	152	204	60	106
TOTAL MINING BRANCH	47.3	591	866	890	690
Extractive Metallurgy	6.4	226	305	49	75
Iron and Steel	8.2	241	172	444*	518*
Institute of Metals	11.7	742*	1400*	1310	511
TOTAL METALS BRANCH	26.3	1209	1877	1803	1104
PETROLEUM BRANCH	24.2	345	690	446	289
Mineral Industry Education	0.6	0	0	5	14
Mineral Economics	1.5	0	0	0	0
TOTAL	100.0	2145	3433	3144	2107

* Ferrous physical metallurgy papers were credited to the Iron and Steel Division until the middle of the year 1948; thereafter all physical metallurgy papers were credited to the Institute of Metals Division.

offer. It has not been the policy of the Institute to accept poor papers just because good papers in the field covered were scarce.

It should also be noted that interests of many Institute members spread over several Divisions. For instance, most members of the Industrial Minerals Division—a commodity Division—are also interested in papers of the Mining and Minerals Beneficiation Divisions.

With the more complete organization of the AIME into its present ten Divisions several of these Divisions are doing, and are going to do, a better job of securing good papers representative of progress in their fields. Further, they are going to expect that the best of these papers will be published, and that they will get a fair share of the total. Appropriate officials and committees of the Institute will do their best in the coming months to estimate what the supply of good papers from the various Divisions will be and to make appropriate allocations of publication funds for 1951. Divisional papers and programs and auxiliary publications committees will be consulted and when the decision is made will then know approximately how much material emanating from them can be published. They can then govern their solicitation and recommendations for acceptance of papers accordingly.

W. Peirce, J. Gillson, M. Haider Head 1951 Ticket of AIME Nominees

O. B. J. Fraser, Chairman of the Nominating Committee, has announced nominations for President, Vice-President, and Directors for 1951. As provided in Art. IX, Sec. 2, of the bylaws, 25 members or associate members may sign and transmit to the Secretary's office prior to Sept. 1 "any complete or partial ticket of nominees."

In such instance, a letter ballot will be forwarded to all members in the United States, Canada, and Mexico, tabulating both the official ballot and any supplementary nominations. If no supplementary nominations are thus received, no letter ballot will be printed, and nominees on the official ballot shall be declared duly elected at the meeting of the board of directors or the executive committee in November.

Nominees for the various offices include: W. M. Peirce, President; J. L. Gillson, Vice-President; M. L. Haider, Vice-President; and T. G. Moore, C. E. Lawall, J. F. Myers, F. W. Libbey, and A. C. Rubel, Directors.

For President

Willis McGerald Peirce, member of the AIME since 1927, is Assistant to the General Manager of the Technical Dept. of the New Jersey Zinc Co., Palmerton, Pa. He has been with the company since 1920 when he received his M.S. degree from Yale. His B.S. was earned at the University of Illinois. He is well known for his work on zinc and for the research organization he has built up. Mr. Peirce was Chairman of the Institute of Metals Div., in 1935, IMD lecturer in 1944, served as Director of the AIME from 1937 to 1943 and from 1949 to date, and as Vice-President from 1940 to 1943.

For Vice-President

Joseph Lincoln Gillson became an AIME member in 1923, when he was an instructor in Mineralogy and Petrography at MIT. He had received his B.S. and M.A. degrees from Northwestern and his M.S. from MIT, where, by 1928, he was an Associate Professor. The following year he returned to Northwestern, as Associate Professor of Economic Geology. In 1930 he joined E. I. du Pont de Nemours & Co., Wilmington, Del. Mr. Gillson was Chairman of the Industrial Minerals Div., AIME, in 1947, and was recently Chairman of the AIME Committee on Democratization.

Michael L. Haider was Chairman of the publications committee of the AIME Petroleum Div., for several years, Chairman of the Petroleum Div., in 1945, and active on numerous other committees. He is Vice-President and General Manager of the Production Dept. of the Imperial Oil Co. Ltd., Toronto, going there about four years ago from the Standard Oil Co. (N.J.). After graduation from Stanford in 1927, he worked for the Portland Cement Co., the Richfield Oil Co., and the Carter Oil Co.

For Director

Thomas Gaunt Moore began his present association with the American Metal Co., New York, in 1935 as Field Engineer in the Mining Dept. Following graduation from Harvard in 1931, he became Geologist in charge of the Morococha mine of Cerro de Pasco. After three years in Peru, he returned to the Harvard graduate school for his Ph.D., which he was granted in 1936. Mr. Moore has been active in New York Section affairs and was Section Chairman in 1948.

Charles E. Lawall, Assistant Vice-President of coal properties for the Chesapeake & Ohio Railway, Huntington, W. Va., was Chairman of the Coal Division, AIME, in 1940, and, with a membership dating back to 1914, has been active in AIME affairs and a frequent contributor to technical literature. Dr. Lawall was made President of West Virginia University in 1939, having been Director of its School of Mines. He had been associated with Pittsburgh Testing Laboratories, New Jersey Zinc Co., Bethlehem Steel Co., and Lehigh University.

John F. Myers, Superintendent of Concentration for the Tennessee Copper Co., Copperhill, Tenn., is one of those who made the organization of the Minerals Beneficiation Div., AIME, a *fait accompli* in 1948, and was its first Chairman. Mr. Myers graduated from Colorado School of Mines in 1913 and went to work for the Butte & Superior Copper Co. He was with American Zinc Co. of Tennessee for a year and New Jersey Zinc Co. for 11 years, joining Tennessee Copper in 1926 as Superintendent of Milling.

Fay W. Libbey, with the Dept. of Geology and Mineral Industries of the State of Oregon in Portland, made his entrance into the mining field in 1906 as night foreman for the Nipissing Mines Co., Cobalt, Ont. Two years later he was Superintendent of Vulture Mines Co., Wickenburg, Ariz., going from there to the custom assay office in Phoenix, and then into mine leasing, oil field work, and consulting. He was Chairman of the Oregon Section in 1942.

Albert C. Rubel, Vice-President of the Union Oil Co. of California, Los Angeles, got his B.S. from the University of Arizona in time to be assayer for Magma Copper for three months before going into the Army in 1917. After separation from the 304th Engineers, he became Geologist for the Commonwealth Petroleum Co. and then the Richmond Levering Co. In 1923 he joined Union Oil Co. as a Geologist, becoming a Director in 1936.

Metals Divisions Nominate 1951 Officers

Extractive Metallurgy Division: Chairman, T. D. Jones; Secretary, E. O. Kirkendall; Executive Committee (until 1954), L. P. Davidson, R. D. Bradford.

Industrial Minerals Division: Chairman, A. B. Cummins; Secretary-Treasurer, D. G. Runner; South-

eastern Vice-Chairman, T. L. Kesler; Rocky Mountain Vice-Chairman, Eugene Callaghan; Eastern Vice-Chairman, H. M. Bannerman; Canadian Vice-Chairman, George F. Jenkins; Western Vice-Chairman, A. C. Bartell; Executive Committee, R. B. Dott, J. A. Barr, Sr., with Paul H. Price as alternate, G. R. Gwinn.

Institute of Metals Division: Chairman, R. M. Brick; Sr. Vice-chairman, W. A. Dean; Vice-chairman; J. H. Scaff; Secretary, E. O. Kirkendall; Executive Committee, J. B. Austin, W. R. Hibbard, Jr., C. H. Samans.

Iron and Steel Division: Chairman, T. L. Joseph; Vice-chairmen, W. C. Kitto, J. B. Austin, E. K. Miller; Executive Committee (until 1954): R. W. Campbell, J. A. Bowers, F. L. Toy.

Mineral Economics Division: Chairman, Richard J. Lund; Vice-chairmen, Granville S. Borden, Julian W. Feiss, Robert P. Koenig; Secretary-Treasurer, John H. Melvin; Executive Committee (until 1954), Evan Just, Russell H. Bennett, George W. Josephson.

"Research in Progress" Headlines IMD Fall Meeting, To Be Held With Metal Show

"Research in Progress," a new feature to be included in the fall meeting program of the Institute of Metals Div., will be based on reports of investigations not sufficiently complete to warrant publication as a technical paper for AIME Transactions. The presentation of such reports, followed by discussion, may be of considerable value to the investigator as well as to others working along similar lines.

Those wishing to participate in this particular feature of the fall meeting, to be held Oct. 23 to 25 at the Sheraton Hotel, Chicago, should advise Ernest Kirkendall, Secretary of the Institute of Metals Div., by Aug. 1. Prior to Aug. 15, three copies of an abstract, not to exceed 500 words, should be submitted. To stimulate interest and discussion, as well as provide members with an idea of what will be discussed at the meeting, these abstracts will appear in the October issue of JOURNAL OF METALS.

IMD, to provide greater service through more valuable meetings, has expanded its program committee. In addition to two vice-chairmen to arrange the traditional type sessions, based on Transactions papers, a vice-chairman has been appointed to aid Local Sections in obtaining speakers, and a vice-chairman has been appointed to arrange special sessions based on non-Transactions papers. Typical of the latter group were the Tube Production Practice Symposium, the symposium on Solidification of Metals and Alloys, and the informal evening session on Recrystallization and Grain Growth, at the Annual Meeting last February.

"Research in Progress" reports may be part of the regular presentations of technical papers, or may be part of a special session either as a symposium or an informal session, depending upon the subject matter covered.

Quota Set at 2500 New Members

"By February, 1951, 2500 new members is our aim," says James A. Douglas, national chairman of the AIME membership committee. "This goal can be reached by the combined efforts of the Local Section membership committees, and the divisional committees with direction and coordination from our committee and the New York office," he continued. "This quota of 2500 is 15 pct of the Institute membership and is 1000 more members than joined in 1941.

"Each Local Section will be given a quota of 15 pct of its membership as a new member target. They will be requested to accept this figure or suggest a quota of their own choosing. A program of attack, successfully used by the New York Section in 1949, has been outlined and forwarded to the sections for their consideration. The overall campaign will be based on teamwork and personal contact."

Mr. Douglas, while acting as membership chairman for the New York Local Section in 1949, accounted for 150 new members.

Coming Events

July 3-7, Gordon Research Conference, AAAS, chemistry and physics of metals, New Hampton School, New Hampton, N. H.

July 10-14, Engineering Institute of Canada, annual meeting, Royal York Hotel, Toronto.

July 25, AIME, Manila Section, Elks Club, Dewey Blvd., Manila, P. I.

Sept. 1, AIME, Minerals Beneficiation Div., Hotel Utah, Salt Lake City.

Aug. 28-31, American Mining Congress, Metal Mining Convention and Exposition, Fair Grounds, Salt Lake City.

Sept. 3-8, American Chemical Society, National Chemical Exposition, Chicago Coliseum, Chicago.

Sept. 5-9, American Chemical Society, sixth national chemical exposition, Chicago Coliseum, Chicago.

Sept. 10-13, American Institute of Chemical Engineers, Radisson House, Minneapolis.

Sept. 15-16, National Society of Professional Engineers, Wheeling.

Sept. 19-21, American Society of Mechanical Engineers, fall meeting, Hotel Sheraton, Worcester, Mass.

Sept. 20, AIME, Carlsbad Potash Section, Riverside Country Club, Carlsbad, N. Mex.

Sept. 22-23, AIME, El Paso Metals Section, Chihuahua, Chih., Mexico.

Sept. 26-29, Assn. of Iron and Steel Engineers, annual meeting and exposition, Cleveland Public Auditorium, Cleveland.

Oct. 3-5, American Institute of Electrical Engineers, Baltimore.

Oct. 4-6, AIME, Petroleum Branch, New Orleans.

Oct. 9-13, AIME, Washington, D. C., Section, Industrial Minerals Div., and Mineral Economics Div., Shoreham Hotel, Washington, D. C.

Oct. 11-12, AIME, Industrial Minerals Div., Rocky Mt. Section, El Paso, Texas.

Oct. 12, AIME, El Paso Metals Section, El Paso, Texas.

Oct. 12-13, AIME, Southern California Section, Metal, Mining, and Petroleum Branches, Elks Club, Los Angeles.

Oct. 13, AIME, Southwestern Section, Open Hearth Committee, Iron and Steel Div., Houston, Texas.

Oct. 17-20, AIME, Industrial Minerals Div., fall meeting, Norman, Okla.

Oct. 20, AIME, Eastern Section, Open Hearth Committee, Iron and Steel Div., fall meeting, Warwick Hotel, Philadelphia.

Oct. 20-21, Engineers' Council for Professional Development, annual meeting, Hotel Tudor Arms, Cleveland.

Oct. 22-24, American Mining Congress, metal and nonmetallic convention, Biltmore Hotel, Los Angeles.

Oct. 23-25, AIME, Coal Div., and **ASME,** Fuels Div., Hotel Statler, Cleveland.

Oct. 23-27, National Metal Congress and Exposition, International Amphitheater, Chicago, Ill. Participating organizations: AIME, Headquarters, Hotel Sheraton; ASM, Headquarters, Palmer House; American Welding Society, Headquarters, Hotel Sherman; Society for Non-Destructive Testing.

Oct. 27, AIME, Southern Ohio Section, Open Hearth Committee, Iron and Steel Div., annual meeting, Deshler-Wallick Hotel, Columbus, Ohio.

Nov. 3, AIME, Pittsburgh Section of Open Hearth Committee, Iron and Steel Div., and Pittsburgh Section, AIME, annual meeting, William Penn Hotel, Pittsburgh.

Nov. 26-Dec. 1, American Society of Mechanical Engineers, annual meeting, Hotel Statler, New York.

Dec. 7-9, AIME, Electric Furnace Steel Conference, Iron and Steel Div., Hotel William Penn, Pittsburgh.

Feb. 19-22, 1951, AIME, annual meeting, Jefferson Hotel; Metals Branch session, Statler Hotel, St. Louis.

Apr. 2-4, 1951, AIME, Open Hearth and Blast Furnace, Coke Oven and Raw Materials Conference, Iron and Steel Div., Statler Hotel, Cleveland.

New Uses for Electronic "Wizards" Foreseen by RCA Lab. Scientist

Electronic "wizards", which can break seconds into a million parts, measure the time it takes a high-velocity bullet to travel an inch, speed the location of oil beneath the ground, and even solve complicated dietary problems, were described by Cyril N. Hoyler, research engineer of the RCA Laboratories, Princeton, N. J., at the Iron and Steel Div., AIME, dinner on May 24.

Cyril N. Hoyler

The high-speed counter or interval timer, using a basic circuit found in a great many electronic computing devices, has a capacity of 100,000 counts a second in the commercial model and up to 10,000,000 counts a second in certain laboratory models. By linking the timer with photoelectric cells, activated by the interruption of light beams, the very high speeds of modern projectiles may be accurately measured.

Mr. Hoyler discussed the RCA Antennalyzer, an electronic device which solves the equations used in the design of a directional antenna system for broadcasting. The analogue computer, an electronic brain, can solve ten equations simultaneously and is a great help in measuring the sound waves projected through a number of strata of different materials in the never-ending search for oil.

Israel Merchant Mill to Roll Merchant Products; Melt Shop Planned

A $3,000,000 steel plant to be known as Israel Rolling Mills, Ltd., is under construction in the industrial zone of Haifa Bay, Israel. Solel Boneh, the workers' union, arranged the financing of the project, and H. A. Brassert Co., New York, is handling the engineering work.

Three rolling mills are under construction. A three-stand, three-high, 18-in. merchant mill, which will take 6-in. billets, will roll small structurals, bars, flats, small channels, and smaller billets for other mills. A five-stand, three-high, 12 in. and a four-stand, three-high, 10-in. merchant and rod mill will roll smaller sections, such as angles, tees, bars, and rod sizes down to No. 5 rod.

The required 6-in. billets will be imported, possibly from Belgium or Yugoslavia and reheated in furnace equipment at the plant. Total capacity of the three mills is expected to be about 60,000 tons of finished product per year. Electrical equipment, rolls, and one furnace are yet to be purchased, quite likely in the United States.

The rolling mills were built by Demag of Germany shortly after the war for delivery to Japan. The equipment was impounded at Dunkirk, and subsequently purchased and delivered to Israel.

It is subsequently planned to add electric furnace melting capacity for producing the required 6-in. billets. Scrap is being stockpiled in preparation for the completion of the project. Much of the scrap was procured in North Africa shortly after the war, and the stockpiling program is being continued.

Alcoa's Texas Aluminum Plant Uses Natural Gas as Power Source

The Pt. Comfort, Texas, aluminum reduction plant, which started operations earlier this year, uses natural gas for a power source. By means of generators driven by internal combustion engines, nominal generating capacity of the plant is set at 120,000 kw. Natural pressure of 400 to 500 psi is reduced in two stages to 60 lb, with a regulator at each engine further reducing the intake pressure to about 6 lb.

Each engine consumes 13,000 cu ft per hr under load, making normal gas consumption of the plant about 30,000,000 cu ft per day. Under normal operating conditions, the total output of the power plant will be about 2,750,000 kw-hr per day.

Except for short periods during World War II and the early days of the aluminum industry, hydroelectric power has been used for the production of aluminum in Alcoa plants. Low cost power being an important consideration in the economical production of aluminum, Pt. Comfort, with its natural gas, was chosen for the construction of the new plant. Gas is received from both off-shore and on-shore wells. One source is near Francitas, Tex., and another is from Matagorda Bay.

The Pt. Comfort plant has a rated capacity of 114,000,000 lb of aluminum per year. Alumina, not made at Pt. Comfort, is shipped in from other Alcoa operations.

Allegheny-Ludlum To Expand Flat Rolling Facilities, Add Research Lab

A $23,600,000 plant improvement program, to be completed in three years, has been inaugurated by the Allegheny-Ludlum Steel Corp., to bring into line with its melting capacity the company's flat rolling facilities. This program is in addition to a five-year program costing $30,000,000 started immediately after the war and now in the final stages of completion.

The new facilities, including a new hot strip mill and additional cold rolling facilities at the Brackenridge, Pa., plant and additional cold rolling equipment at the West Leechburg, Pa., plant, will keep the company's manufacturing capacity in step with changing and increasing demands for high alloy and electrical steels. Further, it will more fully utilize the company's melting capacity, broaden the product range, and improve the quality of product.

The new program also includes the construction of a new research laboratory near Brackenridge. This lab building will be built of stainless steel curtain-walls, and provide the latest facilities for all phases of metallurgical research into high alloy and other specialty steels.

Nothing Is Impossible

A young scientific friend of ours, impressed with the marvels of the atomic age, says he is planning an investigation of the behavior of metals in the temperature range just below absolute zero.

Personals

Franz R. Brotzen has gone to Washington, D. C., where he is employed as a metallurgist at the research station of the Bureau of Mines.

John Chipman, head of the Dept. of Metallurgy at MIT, has been elected a vice-president of the American Society for Metals, Cleveland. **J. B. Austin,** director of research laboratories, U. S. Steel Corp., and **James T. MacKenzie,** chief metallurgist, American Cast Iron Pipe Co., were elected trustees. The board of trustees will also include **Elmer Gammeter,** chief metallurgist, Globe Steel Tubes Co., and **Arthur E. Focke,** chief metallurgist, Diamond Chain Co.

Marcus Digre has returned to Norway to become mill superintendent for the Sydvaranger Iron Ore Co. at Kirkenes.

M. Hansen has been appointed supervisor of nonferrous metals research of Armour Research Foundation of Illinois Institute of Technology, Chicago. He was formerly senior metallurgist.

Stephen B. Hudak has taken a job at the Aliquippa plant of the Jones & Laughlin Steel Corp. Last September he received his degree in metallurgical engineering from the University of Pittsburgh.

Harry B. Hunter has been employed by the Westinghouse Electric Corp., Atomic Power Division, Bettis Field, Homestead, Pa., in the department of metallurgy.

John H. Mackertoom has left the services of the Burma Corp. Ltd., Namtu, Burma, owing to the cessation of operations at the mine, mill, and smelter, on account of political unrest in the country. He has returned to India and is employed by the Metal Corp. of India Ltd. as assistant superintendent in the lead smelter at Tundvo, E.I.R., Manbhum, Bihar.

Donald H. McLaughlin, president of the AIME and of the Homestake Mining Co., gave the commencement address at the Michigan College of Mining and Technology exercises on June 5. Honorary degrees of Doctor of Engineering were conferred on Dr. McLaughlin, on **William M. Cameron,** vice-chairman of the Celanese Corp. of America, and on **Alex D. Chisholm,** general manager of the iron ore division of Pickands, Mather and Co. On June 9, Dr. McLaughlin delivered the commencement address at the Montana School of Mines and received an honorary doctorate in engineering.

Francis M. Rich, vice-president of the Kaiser Steel Corp. in charge of operations at Fontana, Calif., has become general superintendent of the Indiana Harbor Works of the Inland Steel Co. Mr. Rich has worked for Carnegie-Illinois, Wisconsin Steel, Youngstown Sheet & Tube, Republic Steel, and before joining Kaiser in 1946 was works manager of the Steel Co. of Canada, Hamilton, Ont.

Roman Smoluchowski has been promoted to professor of metallurgical engineering at Carnegie Institute of Technology effective Sept. 1. Before joining the Carnegie faculty in 1946 he was a research physicist with General Electric.

John D. Swindale was awarded the degree of B.Sc. (Honorary) at the recent convocation of Birmingham University and since then has taken an appointment as assistant metallurgist at the British Railways Scientific Research Laboratory at Derby, England.

Sam Tour

Sam Tour, chairman of the board of Sam Tour & Co., president of the American Standards Testing Bureau, and of the Graphitized Alloys Corp., has been elected chairman of the Inter Society Corrosion Committee of the National Assn. of Corrosion Engineers.

Kent R. Van Horn becomes associate director of research for the Aluminum Co. of America on Aug. 1. He had been assistant director of research for the company in charge of the branch laboratories at Cleveland since 1945. He will assume his new duties at New Kensington, Pa.

Harold Von Thaden, vice-president of Hewitt-Robins Inc. and general manager of the bulk materials handling equipment company's Robins Engineers Division, has been elected to the board of management of the Engineers' Club, New York City.

Obituaries

Charles Bradley Andrews (Member 1936), assistant to the president of the Taylor Wharton Iron and Steel Co., died April 19. Mr. Andrews was born in Washington, D. C., in 1877, and received his A.B. degree from Princeton in 1898 and his M.E. from Cornell in 1902. He had been with Taylor Wharton for many years.

Charles Swanberg Hurter (Member 1923), retired explosives engineer, died Jan. 2 at St. Petersburg, Fla. He was born at Hyde Park, Mass., in 1875 and received an S.B. degree from MIT in 1898. He worked for various companies in the States and in Canada before becoming technical representative for E. I. du Pont de Nemours & Co. For several years he was with Hercules Powder Co., then returned to du Pont. Mr. Hurter contributed a number of papers to scientific magazines and lectured before many professional societies and at colleges.

Oba Wiser (Member 1914), former consulting metallurgist for the Howe Sound Co., died Feb. 4. He had worked for Chino Copper, Republic Mining and Milling, Metals Exploration, and Britannia Mining & Smelting before becoming consulting metallurgist for Howe Sound in 1925. He retired in 1943, consulting for the company occasionally.

GEORGE SAGE BROOKS

An Appreciation by F. O. Case

George Sage Brooks (Member 1908) died on April 16 in Ottawa, Ill. Born in New Bern, N. Y., in 1882, he studied at Michigan College of Mines. Mr. Brooks worked for the Mineral Point Zinc Co. and in 1919 joined the Anaconda Copper Mining Co. Under his leadership Anaconda became a large factor in the U. S. zinc oxide pigment industry. In 1926 he was sent to Poland to direct the modernization and operation of the Polish Giesche Co. properties, continuing there until forced to leave in 1939 when Poland was invaded by Germany.

Sage Brooks leaves a host of friends who sincerely admired his unpretentious modesty, his keen interest in the world's literary and scientific activities, and above all his great consideration for, and personal loyalty to, his family, friends, and associates. As a leader in his profession he held the respect of his associates and co-workers and at the same time encouraged them to give their best that they might equal the high standard of accomplishment which he required. George Sage Brooks will be deeply missed by his many friends. All who were privileged to know him well were inspired by his personality, sterling character, and astute leadership.

Charles Wesley Davis (Member 1936), chief of the metallurgical division, Region III, of the Bureau of Mines, died on Feb. 21, 1950. During his 34-year career with the Bureau Mr. Davis established a reputation for thoroughness in analytical work, pioneered in the development of new metallurgical processes, and demonstrated unusual ability in the advisory, planning, and administrative work of the metallurgical division. Mr. Davis specialized on the separation of radium and uranium at the rare and precious metals stations of the Bureau at Golden and Reno, making his contribution to the analytical work on lead in the investigations of the age of the earth. In 1929 he began work on the metallurgy of iron ores at Pittsburgh, transferring to College Park in 1933, adding to the information on the methods of magnetic measurements and the application of magnetic measurements to the control of steel slag compositions. Mr. Davis continued his work at Rolla and Boulder City, becoming chief of the Boulder City metallurgical branch in 1945.

Leonard Larson (Member 1918), general superintendent of the reduction plant of the Kennecott Copper Co. at McGill, died Feb. 12, 1950. He had been in poor health for several years. Although he went along with his parents to Wyoming when a youngster, Mr. Larson was born at Roy, Utah, in 1886 and graduated from the University of Utah in 1911. Right after graduation he went to work for the Kennecott Copper Co. as an experiment man and assistant control chemist. As his know-how increased he became roaster engineer, roaster general foreman, assistant smelter superintendent, superintendent of the smelter, and in 1930 was made general superintendent.

NECROLOGY

Date Elected	Name	Date of Death
1896	T. H. Aldrich, Jr.	May 26, 1950
1937	John H. Anderson	May 10, 1950
1900	Frank Ashton	Unknown
1937	John R. Bartlett	May 1950
1940	John M. Basham	Apr. 27, 1950
1908	George S. Brooks	Apr. 16, 1950
1897	Allan J. Clark	Unknown
1950	William H. Gabeler	Apr. 29, 1950
1924	Charles Hart	May 23, 1950
1930	H. M. E. Heinicke	Unknown
1893	W. L. Honnold	May 6, 1950
1928	Chambers Kellar	May 1950
1899	Clancey M. Lewis	May 17, 1950
1902	Mungo Park	Oct. 30, 1949
1942	John P. Wilcox	Feb. 7, 1950
1914	Oba Wiser	Feb. 4, 1950

Proposed for Membership – Metals Branch AIME

Total AIME membership on Mar. 31, 1950, was 16,397; in addition 4037 Student Associates were enrolled.

ADMISSIONS COMMITTEE

E. C. Meagher, Chairman; Albert J. Phillips, Vice-Chairman; George B. Corless, H. P. Croft, Lloyd C. Gibson, Ivan A. Given, F. W. Hanson, T. D. Jones, P. Malozemoff, Richard D. Mollison, and John Sherman.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate.

Alabama

Florence—Bhasin, Krishan K. (C/S–S-J).

California

Berkeley—Tietz, Thomas E. (C/S–S-J).

Colorado

Pueblo—Smith, Rudolph. (M).

Delaware

Wilmington—Tully, John N. (M).

Illinois

Chicago—Bumps, Edson S. (J). Deacon, Alexander J., Jr. (M). Stone, Joseph K., Jr. (M).

New Jersey

Carteret—Osmus, William H. (C/S–S-J).
Mahwah—Hopkins, William E. (C/S–S-J).
Tenafly—Conover, A. E. (A).

New Mexico

Carlsbad—Harty, Hershel A. (M).

New York

New York—Cadoff, Irving B. (J). Warren, Edwin T. (M).
Upton—Atherton, James E., Jr. (J).

Ohio

Youngstown—Burnett, William H. (M).

Pennsylvania

Dravosburg—Hunter, Harry B. (C/S–S-J).
Elwood City—Bagosi, Joseph W. (C/S–S-J).
Erie—Curley, John F. (C/S–S-J).
Gettysburg—Ward, Frederic R. (M).
Library—Shaw, Earl B. (A).
Palmerton—Bechdolt, William R. (J).
York—Hofman, Herman J. (R–M).

Texas

El Paso—Donoso, Julius J. (M). MacCallum, Frank K. (A).

Virginia

Arlington—Digges, Thomas G. (M). Geil, Glen W. (M).

Mexico

Valle-Mexico—Vargas, Fernando G. (M).

Australia

Port Pirie—McMaster, James G. (R,C/S–S-M).

England

Leeds—Hargreaves, Roger. (C/S–JFA-A).

France

Bellevue—Oketani, Shigueo. (M).

Japan

Tokyo—Kasahara, Tamio. (R,C/S–A-M).
Yokahama—Tomiyama, Eitaro. (A).

Modern Composite Metals

by Sidney Siegel

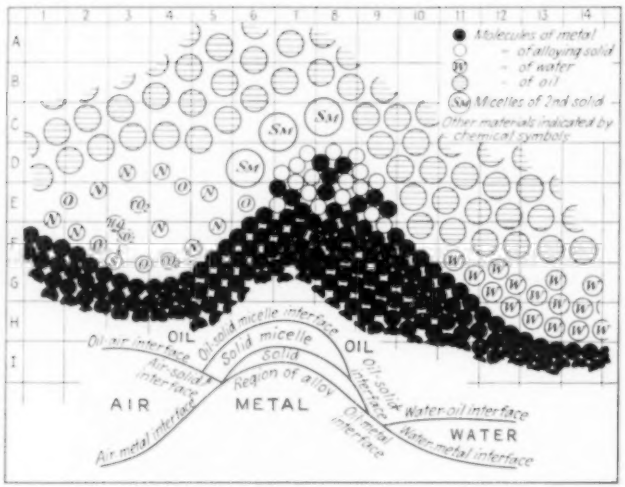

Fig. 1—Various materials adhere to a metal surface, such as gases, alloy, water, and alloyed solids.

MANY new techniques for the bonding together of precious metals to base metal and of various types of base metals to base "metal have been developed since the invention of Sheffield Plate" as requirements have been developed for materials with properties unobtainable in solid metals or as the economics of such material dictated. For many of these composites, the inherent metallurgical characteristics of the materials involved have been so greatly divergent that much scientific skill and ingenuity have been required to develop techniques that would permit bonding and subsequent working of the bonded metal.

Many theories have evolved recently that attempt to explain the bonding of metals and illustrate how these principles are applied in the manufacture of composite or clad metals.

The basic requirements for a bond between two solid metals are the same no matter what the metals are, and the bonding is of the same nature as the forces which hold the different portions of any solid metallic matter together. These forces stem from the electromagnetic field of force which surrounds metal atoms and which is weakly attractive at distances of 10 to 20 atomic diameters, becomes a maximum at a critical atomic distance, and finally becomes repulsive upon closer approach.

When two metal surfaces approach each other, even the smoothest ground finish is so rough from an atomic point of view that they come into actual contact on only a very few points and resist any attempt to cause them to approach more closely. When the repulsive forces which are set up at these points are equal to the attractive forces elsewhere on the surfaces, such a system is at equilibrium.

When the two metal surfaces are pushed together under external pressure, a relatively few **Contact Areas of Repulsion** must withstand the full applied load and, consequently, these few points are under an enormous pressure. As a result, the compressive strength of the material is exceeded, plastic deformation takes place, and there is an increase in the size and number of the **Contact Areas of Repulsion.** When the ap-

Sidney Siegel is development engineer, General Plate Div., Metals & Controls Corp., Attleboro, Mass.

plied load is released, some of these enlarged **Contact Areas of Repulsion** become contact areas at equilibrium (i.e. bonded zones) as the distances between the two surfaces at these zones expand to the equilibrium distance and the metal deforms elastically.

The bonding temperature plays an important role here, since the compressive strength of metals falls off rapidly with temperature and the surfaces can be made to conform more readily at high temperatures. Secondly, with high bonding temperature atomic mobility is increased, thus promoting the migration of base metal atoms into the submicroscopic voids which undoubtedly exist between contact areas at the bond line in the early stages of bonding[1], and also increasing the rate of diffusion of contaminants away from the bond line. It is important to recognize that atomic contact between the two surfaces is essential for diffusion phenomena to take place since diffusion cannot occur over large open areas. This movement of atoms into the voids occurs as a result of surface tension forces which operate to cause a spheroidization of the voids and a decrease in void size. Since the diffusion rate of metals is markedly affected by recrystallization or phase change, choice of bonding temperature with due regard for these phenomena is indicated.

To this point, solid phase bonding mechanism of ideal metal surfaces has been considered. In practice, metals always have adsorbed layers of gases, liquids, or solids, or combinations of such layers at their surface. These contaminants attach themselves to the metal as a result of the unbalanced atomic forces present at a metal surface, which become evident as surface tension or interfacial tension effects.

The nature of the forces present at a metal surface is complex, and will not be discussed deeply here. However, it may be stated that adsorbed layers may be of the van der Waals adsorption type, which is a physical attraction usually of monomolecular layers, in which the energy of attraction is relatively small; or may be of the activated or chemisorption type in which there is a higher energy of attraction and more stable bonding. In addition, polar molecules may be attracted by the dipole moment at the surface of the metal.

Liddiard[2] has presented a diagram, fig. 1, in which he schematically indicates some of the various materials that adhere to a metal surface. Starting from the left-hand side of the diagram, a pocket of air is indicated, containing molecules of carbon dioxide, nitrogen, oxygen, etc., some of them forming an adsorbed layer on the metal. The crosslined circles represent an overall film of oil. In the lower right-hand section, a trapped water pocket is indicated, again exhibiting adsorption at the metal surface. At the oil-water interface, there is a mutual repulsion force. Because of the lower surface tension of oils, there would be undoubtedly a greater attraction between the oil and the metal surface than between the water and metal.

Several systems of solid deposit are shown. In the air pocket there is a sulphur dioxide molecule which in the presence of moisture would combine with the metal and form a sulphide. This is a direct chemical combination resulting in a stable compound. In the area D7, 8, 9, E7, 8, 9, alloying of another solid with the metal is shown, which is not a chemical combination but a physical solid solution of one metal in another. Just above the alloyed area are represented three large micelles (i.e. large groupings of molecules) which can take on an electric charge opposite to the charge at the surface of the metal and are attracted to the metal with a force that depends upon their size and the nature of the electric charge. This picture merely gives a general

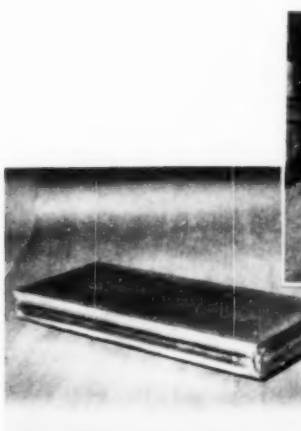

Fig. 2

Fig. 3

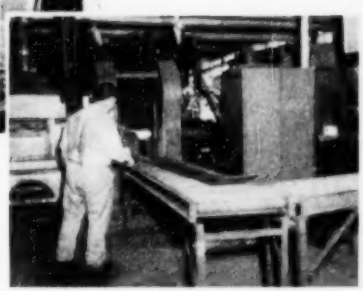

Fig. 4

One bonding technique in composite metal production is to weld around the periphery of two or more slabs of metal, as shown in fig. 2. After heating, the composite slab is hot-rolled, as shown in fig. 3, where the package is shown entering the mill. Fig. 4 shows the completed composite metal strip after a series of reductions, during which time it has been rolled down to desired thickness.

conception of the complex situation existing at a metal surface.

All such layers, with the exception of the layer of alloyed metal, will interfere to some extent with the formation of metal to metal contact and should be removed before bonding. Degreasing, chemical cleaning, such as pickling; and mechanical means, such as grinding, can minimize these layers, although they are never completely removed. Fortunately, as shown by Kinzel[3] in his paper on "Solid Phase Welding," metal oxides such as Fe_2O_3 can readily diffuse away from the bond line into the metal as a function of time and temperature. Durst[4] has observed that copper oxide also diffuses away from the bond line and feels that the speed with which the oxide disappears seems to increase with pressure as well as with high temperature. Such films, therefore, do not make bonding impossible, although their presence is undesirable.

A relatively recent and effective method of removing sorbed surface layers is the use of high temperature in a reducing atmosphere. Still another technique is to utilize shear forces such as are set up by twisting, upsetting in a press, or hot rolling two metals together to rupture and spread out the surface layers. Cooke and Levy[5] in a method suggested to them by shear experiments of Durst recently described a twisting procedure for bonding aluminum to steel or stainless steel. In this process the aluminum oxide which is inevitably present on the surface of aluminum presumably is sheared and pierced by the twisting so that virgin metal surfaces come into contact and effect a bond between the metals. This technique of employing shear forces has been known for some time. The same authors, however, have also found that it is possible under somewhat more restricted conditions to form a bond between aluminum and steel without any lateral movement. This technique is somewhat more difficult to understand and may depend upon diffusion of the aluminum oxide into the base metal.

Bonding Techniques

Composite metal manufacturers employ two different solid phase bonding techniques. One method is to clean and assemble the two metals, protect the mating surfaces from oxidation, and then hot press them at a temperature below the solidus of either metal. Rolling of the metals is done subsequently. A second procedure is to assemble the two metals by welding around the periphery to exclude oxygen, heat the **package**, and then hot roll the composite ingot. The sequence of this technique is shown in figs. 2, 3, and 4. In this procedure, the hot rolling not only supplies the necessary pressure to bring the surfaces of the two metals in contact, but elongates the mating surfaces with the beneficial effects on rupturing interfacial layers. In addition, the hot rolling of the composite ingot brings the material further down towards the thickness at which it is to be used. This solid phase bonding procedure is particularly useful for manufacturing composites wherein both metals involved melt at approximately the same temperature, such as stainless steel on plain carbon steel, the various chromium alloys on invar which are used for thermostatic applications, nickel on iron, etc.

Thus far, only solid phase bonding has been discussed. For many combinations of metals it is much more convenient to utilize the presence of a liquid at the bond line. The problem of bringing the atoms of a liquid in contact with those of a solid metal is obviously much more easily solved since liquids, by their nature, are more mobile than solids. The situation resolves itself to a question of wetting, which can be measured physically by observation of the contact angle made by the liquid on the metal. If the contact angle is zero, the liquid attracts the solid as much as or more than it attracts itself. If the contact angle is 90°, the attraction of the liquid for the solid is half that for itself, while a 180° contact angle indicates no adhesion between the liquid and the solid. Angles of 180° have never been found in nature.

The smaller the contact angle, the greater is the wetting or spreading of a liquid metal. The spreading is affected also by the contour of the solid surface, as can be easily observed by heating a measured quantity of soliver solder on a piece of polished copper and comparing the area over which the solder spreads with the area when the same experiment is performed on a piece of copper that has been grooved by grinding with an abrasive belt. Each scratch mark acts as a capillary, which increases the tendency of the solder to flow.

The problem of removing contaminants from the interface exists in liquid phase bonding too, but here the possibility of using a flux is added to the other techniques described for removing oxides.

Bonding Gold Plate

The bonding of gold plate for the jewelry industry and silver on base metal for the electrical and chemical industries are accomplished by techniques that vary all the way from completely liquid through liquid-solid to solid phase bonding. These may be used to illustrate the advantages and disadvantages of the various methods. Gold plate to be used for jewelry applications requires an extremely fussy bonding technique since the overlay of gold on base metal is so thin when the material is finished (less than 0.0005 in. in many applications) that the slightest imperfection in the bond will show through on the highly polished surface. Tiny unbonded areas, which would not be visible on material with heavy overlays and which certainly affect the overall bond strength very little, show up as undesirable blisters when such material is annealed. Hence, the insistence on absolute cleanliness of mating surfaces and edges, which are usually cleaned on abrasive belts just before assembling. Such composite metals may be bonded by a solid phase welding technique[6] *dry bonding* or may be bonded with the help of a thin foil of silver solder of long plastic range which is heated to a temperature between its liquidus and solidus *moist bonding*, or through the use of a silver solder, which becomes completely liquid at the temperature of bonding *wet bonding*. As might be expected, the pressures required in these three methods are highest for solid phase bonding and decrease

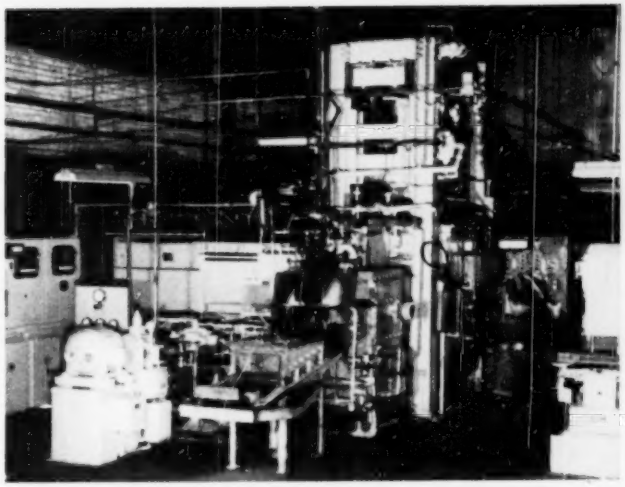

Fig. 5—The latest development in gold plate bonding is this special protective atmosphere bonding furnace where the assembled packages are pressed while being heated and re-pressed in the cooling chamber. This is done in the presence of a reducing atmosphere.

when semi-liquid and liquid solders are present (from 3000 to 4000 psi to 500 to 1000 psi for gold on nonferrous base metals such as copper and its alloys).

The original Sheffield plate bonding procedure was to heat the assembled ingots in air, using a slight amount of flux at the edges to take care of oxidation and using iron wire to hold the two metals together. A solder that became completely molten at bonding temperature usually was employed. This procedure, improved upon only by the substitution of alloy clamps for the iron wire and by the addition of a hydraulic press for clamping the ingots after the solder has started to flow, has persisted to the present day. However, the results of such bonding methods depend heavily upon the skill of the operator. Too little flowing of the solder results in loose edges and large unbonded areas, while the slightest amount of excess heating results in tiny blisters about the size of a pinhead in the finish annealed gold plate.

A better procedure is to use a solder which becomes only partially liquid at bonding temperature, or no solder at all; wrap the entire ingot assembly in sheet metal to exclude air, heat for the proper length of time, determined empirically, in a gas or electric muffle furnace, and finally to squeeze the ingot between the platens of a hydraulic press. This process provides a much larger factor of safety in the elimination of blisters.

Perhaps the latest word in gold plate bonding is the development of special protective atmosphere bonding furnaces, as shown in fig. 5. Here the assembled ingots are pressed automatically while being heated, and then repressed in a cooling chamber, all in the presence of a highly reducing atmosphere, that prevents oxidation of the hot metals and reduces those oxides present. In this furnace, no fluxes or wrapping of the ingots are necessary. The assembled ingots are loaded on pans that are hydraulically pushed through a preheating chamber into a high heat chamber. In the high heat chamber are located the alloy steel platens of a variable pressure hydraulic press that can be employed to press the ingot while it is being heated to the proper bonding temperature. After the metal has been hot pressed, it is ejected by hydraulic ram on to the water cooled platen of a cold press, and pressure is applied in the cold chamber. Following sufficient cooling under pressure, it is mechanically pushed into the air, where it is immediately quenched by water spray.

Silver and its alloys can be bonded to such base metals as copper, brass, monel, and steel in this mechanized furnace by techniques similar to gold plate bonding. When silver is bonded to copper and its alloys, advantage is taken of the low melting eutectic alloy that forms between the two when the metals are heated under pressure. Here, precise temperature control is required to prevent excess alloying. In bonding silver to steel, a similar bond can be obtained by interposing a thin film of copper between the two metals to form a similar eutectic upon heating.

In all of these precious metal combinations the control of assay enters into the consideration of bonding technique. Excessive uncontrolled upsetting during pressing or excessive flowing of solder must be avoided. In such applications the desirability of a long melting range solder and control of bonding temperature between the liquidus and solidus of the solder became evident. Since some liquid is present, high pressures are

Fig. 6—When properly rolled and annealed, copper on aluminum does not have any intermediate layers at the bond line, as shown here.

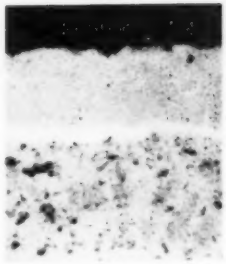

Fig. 7—If the metal in a copper-aluminum composite is overheated during annealing or soldering compound formation occurs and embrittles the bond, as shown here.

unnecessary and at the same time there is not enough liquid to cause excess flowing.

Excessive running of solder in certain instances may be extremely undesirable, because of preferential attack along the grain boundaries of either the base metal or the overlay material as well as because of its effect on assay variation.

The melting of one metal on another is a technique seldom used in bonding precious metals except in the manufacture of silver-solder-flushed material. It is a method that does not lend itself easily to assay control. For base metals on the other hand, it can be a convenient process, particularly where the one metal has a much lower melting point than the other. For thermostatic applications No. 64 brass on invar is frequently made by this method. Retaining strips of chrome iron are welded around an invar bar to form a pan and the brass is simply melted on the invar in the presence of a proper flux. Copper on stainless steel also can be made in this manner.

Sometimes the two metals to be bonded form objectional brittle compounds when they are bonded at high temperature, as in the bonding of aluminum to copper. Here, semi-liquid phase bonding at temperatures where only small quantities of copper-aluminum compound are formed must be employed to minimize the formation of a brittle layer at the bond line. The technique involves the use of an atmosphere furnace to preheat the assembled ingot before it is rapidly entered into the rolls of a hot-rolling mill. The pressure of the hot rolling mill brings the two surfaces into contact and at the same time elongates the materials, the aluminum considerably more than the copper, so that shear forces are exerted at the bond line and spread out whatever compound is present. Succeeding hot and cold rolling passes bring the metal to size.

When properly rolled and annealed, the copper on aluminum is extremely ductile and can be fabricated into all manner of shapes without destroying the bond. Under the microscope, the bond line does not reveal the presence of any intermediate layers, as shown in fig. 6. If the metal is overheated during annealing or soldering, however, compound formation occurs rapidly and embrittles the bond, as shown in fig. 7.

Since aluminum is a very active metal and forms compounds with almost all other metals, the bonding of silver to aluminum, and steel to aluminum are accomplished in much the same way as described for copper to aluminum.

There are many combinations of metals which are undesirable to bond directly because excessive alloying between the two may cause difficulty either in the bonding procedure or in subsequent heat treatment and fabrication. For example, silver on beryllium copper, a desirable composite metal for use as electrical contact arms, must be heat treated at temperatures above 1400 F to develop the age hardening properties of the beryllium copper. At these temperatures, however, a eutectic of the base metal and the silver forms and results in melting at the bond line. The solution is to interpose a thin layer of a third metal, such as iron, between the two to prevent this situation from occurring (Patent No. 2, 474,038).

In bonding cadmium-silver alloys to copper alloys for electrical contacts, a brittle cadmium-copper compound forms at the interface if the two are bonded directly. A fine silver layer placed between the two prevents this condition, thus eliminating embrittlement of the bond despite rolling and annealing operations.

These are but a few examples of the bonding techniques employed and the difficulties encountered in the manufacture of composite metals. Combinations and permutations are almost limitless and represent a constant challenge to the ingenuity of the metallurgist and engineer.

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[3] A. B. Kinzel, *Welding Journal*, December, 1944.

[4] G. Durst, *Metals Progress*, January, 1947.

[5] V. W. Cooke and A. Levy, JOURNAL OF METALS, November, 1949.

[6] E. Davignon, *Metals Handbook ASM* (1948).

The All-Basic Open Hearth . . . European and American

by R. P. Heuer
and
M. A. Fay

Basic refractories used in the open hearth roof, ports, and ends; construction of slag pockets and regenerators; and fuel practices and direct comparisons between furnaces of various design are described in this final part of a two part article. The authors report on research and development completed as well as that projected in basic refractories and their applications.

THE refractories used in European basic roofs are burned chrome-magnesite brick similar in almost every respect to burned chrome-magnesite brick made by American manufacturers. Such brick contain from 60 to 75 pct of chrome ore and a complementary amount of magnesite. Table I shows the chemical analysis and physical properties of the European brick, Radex-E, compared with similar data on several American bricks made by different manufacturers.

No wide differences in characteristics appear. Nothing makes any one brick stand out as superior. The only pronounced difference between the American and European brick is in Al_2O_3 and Cr_2O_3 contents. Such difference has little effect on brick properties.

European literature places emphasis on the effects of chrome ores from various sources on brick. The ore preferred by most European producers comes from Turkey. It is a hard, lumpy ore, low in silica and lime, fairly high in chromic oxide, and relatively uniform in properties and analysis. These characteristics make it a satisfactory refractory constituent. In addition, it is credited with giving brick increased spalling resistance. The other ores with which it has been compared usually have been higher in silica and lime and not as uniform in properties and analysis from one shipment to another. Some of these characteristics may explain the preference for Turkish ore.

R. P. Heuer is vice-president and M. A. Fay is ceramic engineer of General Refractories Co., Philadelphia. *This paper was presented at the AIME Open Hearth Conference, Apr. 10 to 12, in Cincinnati.*

Experience in this country does not indicate that Turkish ore is unique and better in any way. Chrome ores of widely variant analysis can yield equally good results in refractories. The mineral chromite is a spinel consisting of one mol of FeO and one mol of Cr_2O_3. Some MgO can replace the FeO, and Al_2O_3 can replace Cr_2O_3 without much effect on properties. Chrome ores containing considerable amounts of Al_2O_3 are preferred in America for refractories.

To date few laboratory tests have been standardized that show critical items of basic refractory quality. Much work on this is being done in various laboratories. Some characteristics undergoing investigation are iron oxide bursting, hot load strength, and studies of crystal growth in service. From these studies it is hoped that better means of comparing basic refractories quality will be achieved. It is interesting that little study of iron oxide bursting, a characteristic thought to cause basic roof wear, has been done in Europe.

Relatively few European brick have been available for study here. Those examined appear to be almost identical in refractory quality with similar American products. Their iron oxide bursting resistance is not as great as that of some other types of American basic refractories.

Similarly, relatively few competitive trials of American and European brick have been made either here or abroad. Some Radex-E brick were tried in front walls and end walls in this country prior to the war. In this service they gave about the same service as American burned chrome-magnesite brick. American brick made from the same raw materials as Radex-E have yielded similar results.

While such tests have not been exhaustive, they and the laboratory tests indicate a striking similarity between such European brick and American burned chrome-magnesite brick. Therefore, the success of the all-basic furnace in Europe doesn't seem to be the result of better basic refractories.

The brick proved best for basic roof service in this country in competitive trials, which included brick similar to the European burned brick, is a steel plated chemically-bonded chrome-magnesite brick. These brick contain about 60 pct of chrome ore. The remainder is magnesite. The chrome is present only as larger grains, which form a skeleton for the brick and provide volume stability. The magnesite is present as fine material filling the interstices between the chrome grains. In this location, it protects the chrome ore from iron oxide attack. Magnesite can absorb up to four times its weight of Fe_2O_3 without excessive loss of refractoriness. By excluding fine chrome ore from the brick and by protecting the larger chrome ore particles by this grain structure, iron oxide bursting of the brick is effectively inhibited. This brick shows a markedly better resistance to iron oxide bursting than any other chrome-magnesite brick.

The chemically-bonded feature and the steel plating on these brick contribute excellent spalling resistance. Spalling has been considered a chief cause of wear and ultimate failure of basic roofs by several European investigators. The preference for brick made from Turkish chrome ore has been based on a superior spalling resistance of such brick. Some European operators have not been able to use basic roofs satisfactorily in all cold charge operations because of excessive spalling losses. Further, one European observer indicated that the spalling conditions caused by shutting down a furnace for hot repairs and the subsequent rapid reheating, as is common in American practice, likely would cause rapid failure of a European basic roof. As much as 3 to 5 in. of brick might be lost during and shortly after one such shutdown. Upon consideration of these factors and the fact that several American chemically-bonded basic brick roofs have undergone as many as six or seven such shutdowns during one campaign without excessive spalling losses, the superiority of the brick used here is clearly demonstrated.

Unburned chemically-bonded basic brick have advantages for all open hearth basic constructions in addition to their excellent spalling resistance. They are less expensive than burned brick of equivalent composition; have lower thermal conductivity; are more dense and impermeable; are more uniform and true to size and shape; have equal or greater cold mechanical strength; and can be made integral with the steel plating, which is essential to long life of most basic installations.

Incorporation of the steel plate as an integral part of the brick has distinct advantages. It eliminates the handling of loose plates and simplifies brick storage; it virtually eliminates breakage in brick handling; and still more important it promotes increased service life. In service, the plate oxidizes and the oxide product reacts with the brick material bonding together adjacent brick. In diffusing into the brick material it tends to hold the brick material itself together, decreasing spalling and increasing life. The intimate contact between the refractory material and the plate in brick with integral plates promotes this reaction and yields better results. This has been shown by various trials in basic roofs, front walls and end walls, in which all plated refractories have rendered definitely better service than alternately plated and unplated brick of the same composition.

TABLE I

Chemical and Physical Data on Various Burned Chrome Magnesite Refractories

	Radex E	American Brick				
		A	B	C	D	E
Chemical Analysis, Pct						
SiO_2	3-7	5-7	5-7	5-7	5-7	5-7
Al_2O_3	9-14	20-22	20-22	18-20	19-21	20-22
FeO*	8-12	10-13	9-12	9-12	12-14	9-12
CaO	1-2	1-2	1-2	1-2	1-2	1-2
MgO	37-43	33-35	33-36	43-45	38-42	34-37
Cr_2O_3	25-34	23-26	22-24	20-22	20-22	23-25
Bulk Density (oz per cu in)	1.72	1.74	1.74	1.72	1.73	1.72
True Specific Gravity	3.85	3.83	3.85	3.82	3.80	3.84
Porosity, Pct	25	25	21	24	26	25
Cold Crushing Strength, Psi	3000	4000	5000	4000	4500	4500

* *All iron reported as FeO.*

All these things indicate the superiority of chemically-bonded steel-plated refractories for basic roof service. Trials of such brick in proper construction in European basic roofs probably would yield improved results over the present refractories.

The use of chemically-bonded basic refractories requires proper construction techniques.

In service, chemically-bonded brick develop a zone within the brick where the chemical bond has been weakened, but where a ceramic bond has not been formed completely. Although the brick strength is adequate in most cases, if shearing stresses or other unbalanced forces causing movement are applied in this region, some deterioration of the brick can occur in this weaker zone. Therefore, construction must be arranged so that such forces cannot be exerted on this softer zone. This condition does not occur in burned basic brick and they can withstand some greater stress in improper constructions. This explains why burned basic brick have appeared slightly better than chemically-bonded brick in some basic port roof installations in this country. When proper construction, such as described, is applied to furnace port roofs, it is expected that the chemically-bonded brick will demonstrate their superiority over burned products as they have in basic main roofs.

The average results expected from all-basic furnaces in Europe are: 1—Roof life that is 2 to $2\frac{1}{2}$ times as long as that obtained with silica brick. 2—Increased production of about 15 pct. 3—Decreased fuel consumption amounting to from 10 to 15 pct. These three improvements are all necessary to justify the increased initial construction costs, but with these results the all-basic furnace is economical.

American all-basic furnaces fulfill the first two requirements, but have not met the third. Unit roof life of American basic roofs has been from two to three times the unit life of silica roofs. Increased production of from 12 to 16 pct

has been normal for all-basic furnaces. However, instead of decreasing, fuel costs have increased about 10 pct.

The cost of this fuel loss is critical. If fuel cost of American all-basic furnaces was equal to that of silica furnaces, overall cost figures would show them economical; and if fuel savings occurred, they probably would be adopted rapidly. Thus it appears that while marked improvements have been made in designs and refractories for the all-basic furnace, corresponding progress in fuel and combustion practices has not been made. In improvement in this field lies the success of the all-basic furnace in America. Research and endeavors should be predominantly in the direction of improved fuel practice.

The European all-basic furnace operators and engineers appear to have overcome this problem. This situation makes necessary careful study of European fuel practices to discover what advantages they may possess.

Table II shows various data on production rates, fuel rates, and other factors, on several European open hearth furnaces, some of which have been operated both as all-basic and as silica furnaces. Many of these data required calculation to obtain comparable figures so that they are only good approximations of existing conditions. However, considering the fuels used, amount of cold charge, and other conditions, they show that European furnaces operate rapidly and with good fuel efficiency by American standards. Since, from this, it appears that the results of fuel practices on silica furnaces in Europe and America are not widely variant, it is likely that some fuel practices on European all-basic furnaces are better than those used here.

Because the majority of European furnaces are low Btu value gas-fired, European fuel practice is closely allied with port-end design and construction. Most furnaces have divided uptakes, slag pockets, and checker chambers for preheating gaseous fuel and air. Where liquid fuels or high Btu value gases are used, port designs still reflect the characteristics essential to operation with preheated gas fuel. In such arrangements, the incoming air stream is directed to mix with the fuel stream and to carry the resulting flame to its proper position in the furnace chamber.

The **classical** design for ports of such furnaces is shown in fig. 10. Preheated fuel gas is delivered into the furnace chamber at or near the bridge wall through a centrally located gas uptake and port. The preheated air is brought in through uptakes on either side of the gas uptake and is carried above the gas port, then turned and directed down toward and around the gas stream by the sloping port roof. The air mixes with the fuel, starting the flame and carrying it across the close to the surface of the bath. The difficulty with this construction is that the entire gas port and the division walls between the air and gas uptakes are heated on both sides. Erosion of refractories is apt to be rapid. When this occurs the gas streams lose velocity and direction, and combustion characteristics suffer. The furnace becomes less sharp. When basic refractories are used in such construction in place of silica, wear is decreased, but is still too great for long periods of proper operation. Until about 20 years ago, silica refractories were used in end constructions almost exclusively. Since that time, basic refractories have been used increasingly.

More than 100 different designs have been sug-

TABLE II

Production Fuel and Other Data on Various European Furnaces

Furnace	A		B	C		D-1		D-2	E		F	G	H
Rated Capacity, Tons	75	75	35	50	50	35	35	120	50	50	85	180	80
Type	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Tilting	Stationary	Stationary	Stationary	Tilting	Tilting
Refractories													
Main Roof	Basic	Silica	Basic	Silica	Silica	Basic	Silica	Silica	Basic	Silica	Basic	Silica	Silica
Port Roof	Basic	Basic	Basic	Basic	Silica	Basic	Basic	——	Basic	——	Basic	——	——
Fuel	Mixed B.F. and Coke Oven Gas	Mixed B.F. and Coke Oven Gas	Oil	Producer Gas	Producer Gas	Coke Oven Gas and Pitch	Coke Oven Gas and Pitch	Low Btu Gas	Low Btu Gas	Low Btu Gas	Low Btu Gas	Low Btu Gas	Low Btu Gas
Charge													
Blown Metal	70 Pct	70 Pct	No	No	No	No	No	No	No	No	?	Yes	Yes
Hot Metal	No	No	No	No	No	35 Pct	35 Pct	Yes	No	No	?	No	No
Cold Pig	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	?	No	No
Scrap	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	?	Yes	No
Roof Life, No. of heats	1000 to 2500	——	530	900*	300*	1000 to 1300	350 to 400	——	900	600	1100 to 1200	——	——
Production** Tons per Hr	16.5	16.0	9.5	8.9	7.8	7.2	6.3	13.7	8.0	7.3	——	12.6	13.7
Tons per Hr per 1000 Sq Ft hearth area	38.2	37.0	21.0	——	——	24.8	21.5	28.8	——	——	——	27.0	28.0
Fuel Rate, (Approx) MM Btu per Ton	——	——	3.2	4.0	4.8	——	——	3.6	——	——	——	——	4.4

* *Port Roof life only.*

** *Figures on Charge to Tap basis.*

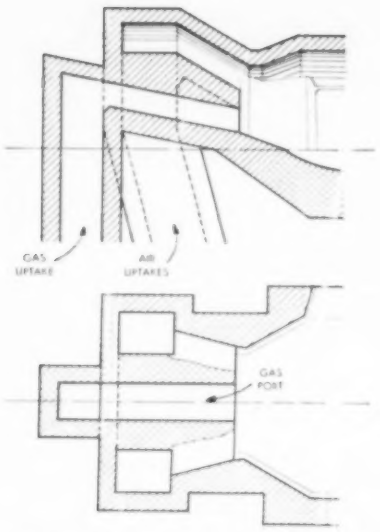


Fig. 19—Port end arrangement of European classical design preheated gas-fired furnace.

gested to improve on the so-called **classical** arrangement. Of these, one design has been successful and has come into wide use in Europe. This design was first developed about 1910, but because of the rapidity of wear of silica was unsuccessful until basic refractories were used. With the institution of the increased use of basic refractories in open hearth furnaces generally, a basic brick manufacturer, the Austro-American Magnesite Co., started a special department of open hearth furnace design to develop open hearth designs that would best utilize the properties of basic refractories. The fundamentals of the gas flow were studied and a system was developed that promotes streamlined flow with least turbulence of all gas streams through the furnace. It tends to promote optimum combustion conditions and control. Consideration was given also to flow direction with relation to refractory walls to decrease refractory wear. The system and design developed from the earlier work of about 1910 is known as the Maerz system, after the originator, who gave his name to the subsidiary organization of the brick company, the Maerz Furnace Co.

The Maerz port is shown in fig. 11. Some of the features of this construction are: 1—The air ports are moved closer to the furnace bath and the air uptakes are separated from the gas uptake. 2—No restrictions, as knuckles or monkey walls, are used. In effect, the furnace chamber extends from end wall to end wall instead of from knuckle to knuckle. 3—Air uptakes are restricted as compared with **classical** design uptakes, providing for incoming air at higher velocities. 4—Thinner refractory walls are used generally. 5—With the smaller sections and thinner walls, some parts of the port are made portable. Such sections can be laid up in steel frameworks away from the furnace and substituted in the furnace structure at will. All of these things were made possible by the increased life obtained from basic refractories.

Furnaces fired with liquid fuel or cold gas fuels use the Maerz design with the gas port omitted, or a design according to the Maerz system which includes a single air uptake.

Since American furnaces are so predominantly liquid fuel or cold gas fired, for comparative purposes, only the function of Maerz ports with such fuels will be described. The conditions of gas flow through the single uptake furnace are simple. The port is arranged to direct the air downward toward and across the bath. There is only one turn in the direction of air flow. The restriction of the end, from front to back, gives the air a considerable velocity towards the center of the furnace. It picks up the fuel stream, mixes with it, and carries it across the bath.

The fuel, either gas or oil, comes into the furnace through one or more burners usually located in the end wall. The burner tip usually is back close to the end wall. Occasionally, burners are located at either side and in front of the air uptake. Auxiliary oil burners for carburetting gas flames sometimes are used in these positions.

With gas fuel, relatively low gas pressures are normal. Oil usually is atomized mechanically. High pressure oil is given a strong swirling action by a special (Körting) nozzle and is discharged from the nozzle in a cone shape. A small amount of low pressure air blown through a jacket, concentric around the burner, molds the shape of the oil cone to the desired length to diameter ratio. Mixing of the air and fuel streams is achieved by the difference in their velocities.

Such ends are constructed entirely of basic brick. Usually the port roof is built in the same way as basic main roofs, although in some cases the span across the port is so small that sprung construction can be used. Because of the restriction of the end and resultant high velocities of exhaust gases, usually it is necessary to make an intermediate repair of the port roof knuckle and

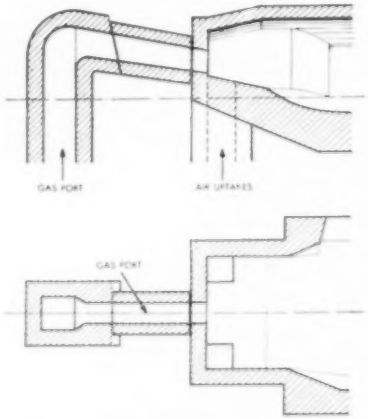


Fig. 11—Port end arrangement of a preheated gas-fired Maerz furnace.

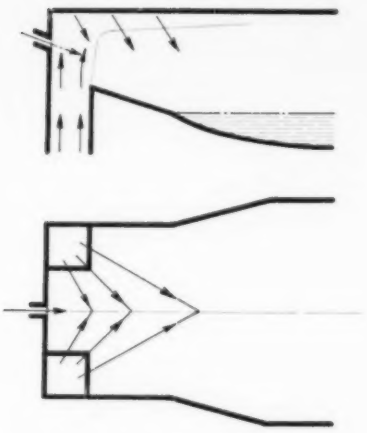


Fig. 12—Incoming air-flow pattern through the port end of a divided uptake Maerz furnace.

the end wall above floor level during each basic main roof campaign. Other sections last throughout such furnace runs without repair.

The flow conditions through the divided uptake Maerz port are more complex. Fig. 12 shows a diagram of such flow. The incoming air is given high velocity upward by the restricted uptakes. It travels to the roof where it is deflected in the directions shown by the arrows. The two air streams meet at the center of the roof and form a strong downward current.

The fuel is introduced through a burner or burners in the end wall. The downward moving air impinges on the fuel stream, promoting rapid mixing. The degree of mixing achieved is determined by the air velocity, which in turn is determined by the cross-sectional area of the air uptakes. Because of this, no restrictions such as knuckles in the roof or monkey walls, are needed to promote mixing. Therefore, the roof is high above the bridge wall where it is not as liable to wear away rapidly. The uptake area needed to give the necessary air velocity is about one third of that on most American furnaces.

These ports also are built entirely of basic brick. The roof is built in the same manner as all-basic roofs. The air uptakes are purposely separated at considerable distance so that the end is not constricted, as in the case of the single uptake furnace. This decreases wear of the port refractories and makes uptake walls readily accessible from the outside. The life of all parts of the port is long, usually an entire basic main roof campaign without repair.

Despite the restricted uptakes, wear of uptake refractories is not excessive. In the Maerz port, the exhaust gases are drawn off downward, directly from the furnace chamber. They move at relatively slow velocity into the furnace end, because of the absence of restrictions, then are pulled down the uptakes at higher velocity. At no point does the exhaust gas stream impinge on a refractory wall at high velocity. Although they do move through the uptake at high velocity, they are moving parallel to the wall face. Thus, refractory wear is not great.

In contrast to this arrangement, most American furnaces have a restriction at the throat which gives exhaust gases from the furnace chamber considerable velocity toward the end wall. The gases hit the end wall and turn down the uptake. Only a portion of the available uptake area is effectively used, most of the gas passing down close to the end wall. Immediately behind the bridge wall a swirl or eddy current usually is set up. The area occupied by this eddy current serves no useful purpose. Because of the impingement of the exhaust gas stream, refractory wear is apt to be rapid at this point. Increasing uptake area does not decrease this wear, as has been shown by basic end furnaces with no burner arches. End wall wear in these furnaces has been as great or greater than that of the same furnaces with burner arches.

Both the single and double uptake Maerz end constructions are smaller than American ends or even basic ends of American design. Figs. 13 and 14 show an American basic end with the Maerz construction superimposed on the drawing in heavy lines. Because of the difference in size, the refractory requirements for the Maerz end are less than for American designs. Similarly, replacements are small. It is probable that overall end refractory consumption for initial construction and repairs of Maerz design ends would be considerably less than that of the American designed ends.

Such construction is possible only with basic refractories, which are more expensive than silica. However, because of the decrease in refractory requirements, overall refractory costs should decrease. American basic ends have lower refractory costs than silica construction, as has been proved on more than 30 furnaces. The Maerz construction should have lower refractory costs.

Because of the small size of the Maerz ends, they offer possible large increases in furnace capacity. If the end walls of the Maerz and American designs were made to coincide in figs. 13 and 14, the furnace bath could be made from 10 to 15 pct larger without changing the area occupied by present American construction. This offers greater possibility for increasing furnace capacity in American shops than any other known means.

In England, relatively few Maerz furnaces are used. There, also, a trend toward restricted uptake areas and increased incoming air velocity is progressing. They have found that large uptakes promote unpredictable local wear of the furnace ends without benefit to combustion practice. Some English operators feel that uptake area for a furnace of 165 tons should be no more than 50 sq ft and some experimental constructions are being tried with even smaller uptakes.

Other design features arousing interest in England at present are: 1—The possibilities of radially suspended basic roofs that are level from one end of the furnace to the other; that is, no port roof sloping sections. 2—The use of single, centrally located, uptakes of width only about one-half of that of the main arch. 3—The possi-

bilities of multiple burners. 4—The possibility of decreasing end wall wear by making it sloping. If the end wall is inclined at about 20° from the vertical, increased life has resulted on some trials. All but the last of these things are like features of the Maerz designs.

Trends in design of American port ends have been in striking contrast to the European and English developments. In general, for the past 20 years American furnaces have been built with increasingly larger end constructions and uptake areas.

This removes the conventionally used silica refractories as far as possible from positions where they wear rapidly. It has been possible to do this by the use of restriction of the furnace throat to increase air velocity into the furnace chamber and by the use of driven fuels. Steam atomized liquid fuels or high pressure gas can be directed and carried to the desired position in the furnace chamber by their own high entering velocity.

Even when basic refractories have been used in ends, with decreased wear, the trend toward larger uptake areas continued. Several furnaces were built without burner arches and the end wide open. On most furnaces, lower production rates and higher fuel rates resulted. When burner arches were reinstalled in these furnaces, production rates increased and fuel rates dropped.

Table III shows data on five basic end furnaces, comparing production and fuel rates with varying uptake areas. Data on comparable silica end furnaces are shown in some cases. Also shown are data on a single uptake furnace, furnace F, on which the pit and checker side walls were moved inward so that the uptake area was close to that of similar size silica furnaces.

Study of these data show the adverse effect of too large uptake area. Since, in most cases, no changes in burners or furnace throat were made during these runs, the only logical explanation for the improvement with restricted uptake area is the resultant increased incoming air velocity. This probably promotes better mixing of air and fuel, causing higher flame temperature (sharper flames) and faster melting.

Short, hot, sharp melting flames are characteristic of European open hearths. Highest possible flame temperature is wanted. This is desirable for fastest melting of cold charges by convection heating. However, such flames are not as highly luminous as some of lower temperature. In recent years, American practices have stressed the need for high luminosity flames, which are better for heating molten materials by radiant heating. The optimum conditions for scrap plus hot metal operations would be high flame temperature flames of lower luminosity and convection heating from the start of charge until the heat is under cover, and the highest luminosity flames and radiant heating for the balance of the heat.

Properly directed, high velocity incoming air should help in achieving both such flame characteristics in bringing faster mixing of the air with fuel. This would promote faster combustion and higher flame temperatures. With better mixing of the air and fuel, it should be possible to decrease the amount of steam used for atomization of liquid fuels. As much as 5 pct of the total heat input into the furnace can be absorbed by this steam. Further, the steam is heated within the flame, affecting flame temperature more drastically than indicated by its overall effect. Any decrease of steam input while the rate of combustion is maintained would increase flame

TABLE III
Variation of Fuel and Production Rate with Uptake Area on American Basic End Furnaces.

Furnace	A	Average of Silica End Furnaces, Comparable to A	B	C	D	Average of Silica End Furnaces, Comparable to D	E	F	Average of Silica End, Divided Uptake Furnaces, Comparable to F
Rated Capacity, Tons	175	175	175	125	125	110	110	125	125	125	120	120	175	175
Practice														
Hot Metal and Scrap	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All Cold Charge	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No
Uptake Area, Sq. Ft. (one end)	114	86.5	86.5	79	47.5	77.6	60.4	*	45.5	45.5	108	91		
No. of Heats in Comparison	586	302	—	148	156	73	184	428	1133	—	41	135	790	—
Production, Tons per Hr	12.9	14.5	13.5	9.65	9.82	9.61	10.53	10.9	11.8	11.4	9.6	11.6	13.66	13.05
Fuel Rate, MM Btu per ton	3.76	3.36	3.60	5.80	5.44	4.09	3.89	4.37	4.07	4.15	—	—	4.51	4.45

* *Area not known but with badly eroded uptake walls and burner arches.*

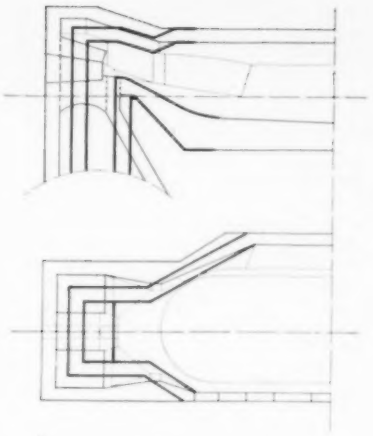


Fig. 13—A single uptake Maerz furnace end, superimposed over a typical American basic end.

temperature and improve convection heating. Most European liquid fuel fired furnaces do not use any atomizing steam.

When highly luminous flames are desired, even less steam for atomization might be used. Only enough steam to atomize the liquid fuel poorly would be needed and the air stream would act to carry the flame to the desired position in the furnace. Those liquid fuel particles that burn early in the flame development should burn faster with better air mixing, creating higher temperatures, more cracking of the unburned fuel, and more luminous flames.

The disadvantages of steam atomization have been recognized and other atomizing agents have been tried. Compressed air has been used in most such trials. It has not been satisfactory because of the high costs of preheating and compressing equipment, and because it is a less efficient atomizer than steam. Consequently, even though high velocity incoming air were to be used in American furnaces, steam would continue to be the atomizing agent.

Operating data on American basic end furnaces, theoretical considerations, and European and English operating experience all suggest possible improvement of American practice through the use of directed, higher velocity incoming air obtained by restriction of uptake area. Further, it appears that this could be done economically by careful design of furnace end structures, taking into account gas flow, patterns, etc., and the use of basic refractories. It seems probable that such practice is largely responsible for the excellent fuel and production records of European all-basic open hearths. Certainly on the basis of these data, it is indicated that exhaustive study be given to fuel practices and their relationship to port design, uptake size, gas flow patterns, etc. It appears worthwhile to install and study Maerz furnaces in America. Many improvements of American practice might be achieved.

The slag pocket designs of European open hearth furnaces are like those of American furnaces. They normally are built of silica refractories even though the end construction above them is basic. Because of this, slag deposits are hard and glassy as in American silica end furnaces. The more extensive use of basic refractories and the resulting almost granular slag deposits of American basic end furnaces promote faster and more economical furnace rebuilding.

Regenerator chambers of most European furnaces are about the same width as those on American furnaces, but usually are shorter and deeper. With these conditions, the length of gas travel through the checker setting approaches that of gas in American two-pass checkers. Most checker settings are the solid wall, vertical flue, variety.

Refractories used are fireclay brick. The quality of European fireclays is below that of American materials, in that they are less refractory, containing less Al_2O_3 and more fluxing constituents. Consequently, checker life is shorter in Europe. Frequently, checkers are replaced after each basic main roof campaign.

Checker life of European furnaces is further decreased by virtue of higher operating temperatures. In most cases checker temperatures are from 150° to 250° F higher than in American furnaces.

One reason for the higher checker temperatures is the small furnace end structures. Small ends have little heat capacity and deliver exhaust gases to the checker chambers at higher temperatures. Because of this, European furnace checkers accomplish a greater amount of air preheating than checkers of American furnaces, in which a substantial amount of air preheating is done in the end structure.

Very few European furnaces are equipped with waste heat boilers, and forced drafting has not

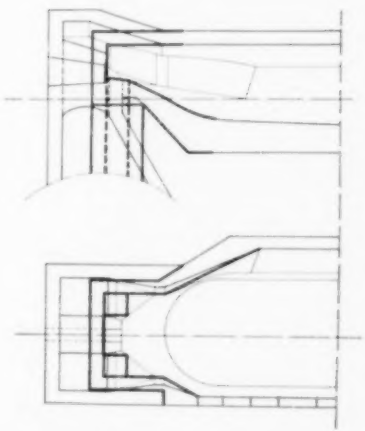


Fig. 14—A divided uptake Maerz furnace end, superimposed over a typical American basic end.

come into wide use. Natural draft is usual. Stacks for European furnaces are normally higher than those of American furnaces, even those for furnaces operated on natural draft. The reason for these high stacks is not that more draft is needed because of the restricted uptakes. The draft is needed to pull a proper proportion of the gas through the small gas ports of furnaces fired with 200 to 300 Btu content preheated gas. In such furnaces, dampers in the flues behind the air checkers are kept partially closed. Present draft on American furnaces would be ample to exhaust the combustion products through restricted upstakes. The additional draft required to overcome the effects of the uptake restriction is small compared to the total draft losses throughout the furnace system.

Summarizing all the foregoing comparisons and discussions of all-basic constructions, furnace designs, refractories, and fuel practices, many similarities and differences in American and European open hearths are evident. There are valid reasons for the existing differences in practice. However, it appears probable that improvement of some American practices could result from consideration of European techniques. In other cases the reverse situation is apparent. Some of the more outstanding of such items are:

1—European and American basic roof designs are almost identical in engineering principles. Some details of the American design—complete suspension, tangential skewback spring arrangement, accessibility of all parts of the roof for hot patching—make it better suited for American operations.

2—European burned basic refractories have no advantages over similar American products. Conversely, the chemically-bonded steel plated basic brick, which have proved most successful here, offer considerable possible improvement to European basic open hearth furnaces in smaller spalling losses, lower heat loss, lower costs and ease of handling.

3—The excellent fuel practice obtained under adverse conditions on European furnaces suggests that revision of American furnace port ends in the direction of and approaching Maerz furnace designs might yield substantial improvements. Factors that should be considered in making such changes include: Fuel, air and exhaust gas flow patterns; uptake size and its effect on incoming air velocity; and amount of steam required for oil atomization.

Savings and improvements that might result from such changes are: Lower refractories consumption and decreased refractories costs by virtue of smaller end constructions and small areas requiring repairs; possible increases in furnace capacities; and possible improvement of fuel rates.

4—With the smaller ends of European furnaces, high checker temperatures are normal.

5—Other items of furnace design and construction—bottoms, front and back walls, slag pockets, and flues—are very similar in Europe and in America. There is no indication of improvement of American practices from use of European techniques in these fields.

The authors of this paper are greatly indebted to Franz Bartu, chief engineer of the Maerz Furnace Co., Millstatt, Austria, for the preparation of several of the drawings and invaluable assistance and advice in making the comparisons and expositions of European ideas of furnace design contained herein. A. J. Mann of the M. H. Detrick Co., Ltd., London, also contributed various helpful ideas and information. It is hoped that their contributions will be widely recognized.

Belt Conveyors Handle Liberian Ore

ONE of the main difficulties in the development of the Bomi Hills iron ore operation, Republic Steel Corp.'s Liberian development, is in getting the ore aboard ship for transport to the United States. To handle the huge quantities of ore required, a dockside conveyor installation has been designed that will stockpile 150,000 tons of ore at all times and will deliver the ore to ships at a rate of 2500 tons an hr. Provisions have been made to handle double this tonnage in the future.

Ore is brought from the mines, about 100 miles inland, on railroad cars to the installation at Monrovia, capital and main port of Liberia. Here, the ore is taken by belt conveyors to the storage area where it is stockpiled. Upon arrival of a ship, the handling system reclaims the ore from storage and delivers it directly to the dock where a traveling ship-loading tower with a boom conveyor takes over.

The tower moves along the dock the length of the vessel, with the boom shuttling across the ship. This permits the ore to be properly and evenly stored in the hold. The double action of the tower and the boom make it unnecessary to move the ship during loading.

The dockside installation, estimated to cost $500,000, will take about a year to build. When completed it will have seven conveyors totalling 2400 ft in length, and the system will require about 5000 ft of belting.

Consideration is being given a long line belt conveyor installation at the U. S. Steel Corp.'s Cerro Bolivar enterprise in Venezuela. A conveyor system has been suggested that would cut through the jungle carrying the ore from the mine to water transportation.

Development of Mechanical Puncher at the McGill Smelter*

by Leonard Larson

SMELTERMEN in the copper industry know that punching the tuyeres of a copper converter is a difficult, disagreeable, and at times a hazardous job. Knowing this, many men in the industry have given serious consideration to punching by mechanical means. As evidence of such consideration, a great many patents have been issued covering various mechanical devices or machines for doing this task.

In 1942, as war-created manpower shortages became more acute, it became increasingly difficult to get men to punch tuyeres. Faced with this situation at the McGill smelter, it was decided that an all-out effort should be made to develop some sort of a mechanical punching device. The various patents were studied over thoroughly but none of the devices seemed suitable, all were discarded and it was decided to develop one, using the ideas of the personnel at McGill.

* Pat. No. 2,432,996—Apparatus for Punching Tuyeres of Copper Converters and the Like—was issued to the author and Byron T. Berge, Mechanical Department Engineer, joint inventor, and assigned to Kennecott Copper Corp., Dec. 23, 1947. Patents covering recent improvements have been applied for.

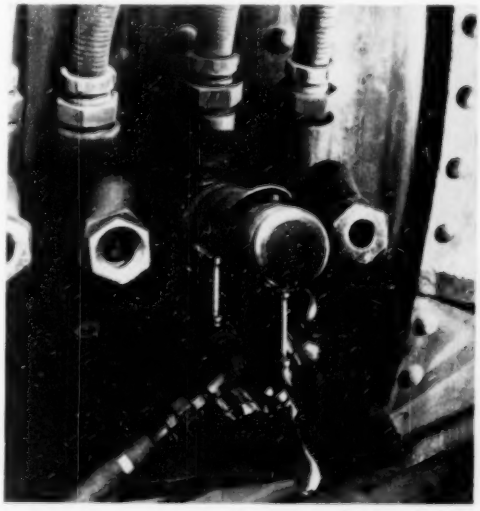
Initial test work indicated that a separate punching device should be attached to each tuyere. This meant that an adapter would have to be developed which would accommodate such a device; the adapter to be so constructed that it could be substituted for the regular Dyblie valve head, and be punched either by mechanical means or by hand. Also a method for quickly attaching or detaching the punching unit would have to be devised. If the punching unit was attached to the adapter, then the punch rod and tip would have to remain inside of and reciprocate within the tuyere pipe. This last requirement meant that the punching device, the adapter, the piston rod, and punch rod must be in perfect alignment. The whole arrangement thus would become an integral part of the converter and would rotate along with the tuyere line to all the positions required for converter operation. If the puncher was to rotate with the converter, there was also a problem of limited clearance. The construction of a device to meet all of these conditions imposed many problems.

In the latter part of 1942, two pieces of equipment were constructed and tried out under test-stand conditions. Both of these devices were very crude, but test-stand operation indicated that progress was being made. Neither of the units was considered good enough to be attached to and tried out on a tuyere of an operating converter.

In May 1943, work was started on another device and in August of that year it was attached to and actually punched a single tuyere of a converter on an experimental basis (fig. 1). This unit was essentially a cylinder 3 in. in diam and about 15 in. long inside. Valve ports were so located as to provide a 1-in. cushion on each end of the stroke. The cylinder ports were piped to a $^{3}/_{4}$-in. four-way disk valve. High pressure air (90 psi) was delivered to the valve by means of a long hose, thus making it possible to supply air to the device at all operating positions of the converter. The forward and return punching strokes were accomplished by shifting the valve handle as required. With the $^{3}/_{4}$-in. valve, stroke velocities from 15 to 18 fps were achieved. Punching with this experimental arrangement was carried on for some time, but many difficulties were encountered. The punch rod tips often stuck in the tuyere accretion, indicating that more energy of some sort was necessary to avoid sticking the punch rod.

To overcome sticking, experiments continued with a speeded up unit and although progress was made, troubles of various kinds continued to appear. On this unit, piston cup seals passed the valve ports which proved to be of very poor construction. Also the piston, driven forward at approximately 28 fps, would often bottom metal to metal in the forward end of the cylinder causing both mechanical and operational trouble. Sometimes the punch rod and at other times the piston rod would break loose and be shot through the tuyere pipe into the converter. Bottoming and poor timing of valve reversal caused a bounce and a hesitation at the end of the forward stroke, with the result that the punch rod

Fig. 1—First mechanical puncher installed and operated on a converter at McGill, August 1943.



LEONARD LARSON, deceased, was a Member AIME and General Superintendent of Reduction Plant, Kennecott Copper Corp., Nevada Mines Div., McGill, Nev.

AIME New York Meeting, Feb. 1950.

TP 2870 D. Discussion (2 copies) may be sent to Transactions *AIME before Aug. 30, 1950. Manuscript received Dec. 2, 1949.*

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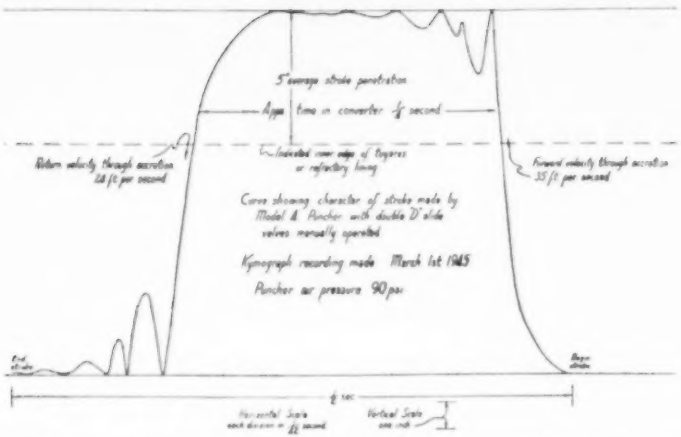
5" average stroke penetration
Approx time in converter 1/5 second
Return velocity through excretion 18 ft per second
Unlocked inner edge of tuyeres or refractory lining
Forward velocity through excretion 35 ft per second
Curve showing character of stroke made by Model 4 Puncher with double D slide valves manually operated
Kymograph recording made March 1st 1945
Puncher air pressure 90 psi
1/2 sec
Horizontal Scale each division = 1/5 second
Vertical Scale one inch

Fig. 2—Kymograph recording of Model 4 puncher stroke, March 1945.

tips still often stuck in the tuyere obstruction. Experience over several months with this unit demonstrated that progress was being made, but it became evident that the unit was not practical and something better would have to be developed.

Experience indicated that a unit with self-contained D-type slide valves would be more practicable. This new type unit, as constructed, had a 3-in. ID by about 15-in. long power cylinder, with a valve chest directly above. The valve chest contained two D-slide valves—one near each end. This new unit, called Model 4, was tried out on a single tuyere of a converter in November 1944 and performed more satisfactorily than the previous models. The inlet valve port was adjusted to give a forward stroke velocity of around 35 fps because previous experience had indicated that this was fast enough to pierce the tuyere pipe obstruction successfully.

Early in 1945, a special testing apparatus was built so that accurate measurements of stroke velocities could be made. The new testing machine not only measured and recorded the stroke velocities, but also determined the characteristics of the strokes. When the testing machine became available, the punching stroke of the Model 4 unit was checked for velocity and character. This machine or "kymograph" showed that the piston always bottomed on the forward cylinder head and usually struck the rear head on the return stroke (fig. 2). Kymograph recordings showed that manual stroke reversal was almost always slow, and that there was a pause and one or more bounces at the end of the forward stroke.

In spite of the troubles encountered, construction was undertaken on additional units of this model. In June 1945, five Model 4 units were attached to the tuyere adapters on one end of a converter. Two more units were available as spares, so it was hoped that five punchers could be kept in service on a three-shift basis on a converter. It soon became apparent that the three-shift operation was too much for the units as constructed. Bottoming continued to occur, and punch rod tips and even piston rods were sometimes shot into the converter.

Since most of the breakage occurred on the forward stroke, it was decided to close off the forward valve port entirely, thus using the entire cylinder to form an air cushion. Results were surprising. The 90-lb air pressure drove the piston rapidly forward to within an inch or so of the cylinder head where it stopped and reversed. With proper manipulation of the valve handle it was found that the piston would achieve a maximum forward velocity of about 40 fps at a point near the end of the cylinder. Here it paused momentarily, made a double bounce of a few inches, then returned toward the starting point. The maximum velocity on the return stroke was about 17 fps (fig. 3-*a*). After many trials with the closed port unit, it was realized that manual reversal of the valve handle could not be depended upon to produce a satisfactory punching stroke.

In the late summer of 1945 work was started on the development and construction of a valve reversal mechanism which, it was hoped, would result in an "ideal" punching stroke. The accomplishment of such a stroke would involve perfect timing and the exact coordination of many moving parts. Finally, after months of work, many experiments, and the recording of hundreds of strokes, one Model 4 unit was rebuilt and a valve reversal mechanism installed. This unit, after necessary adjustments, produced a nearly perfect punching stroke (fig. 3-*b*). It was found that a back pressure of about 5 psi in the front of the piston was necessary to insure complete return of the piston. It also served the purpose of keeping the piston at rest in the rear end of the cylinder.

With the proper valve opening, the unit recorded a maximum forward velocity of about 40 fps, about 1/50 of a second delay for complete reversal, and a maximum return velocity of about 30 fps. Action of the device was essentially as follows: Pushing the valve handle opened the inlet port, thus forcing the piston rapidly forward. The air trapped in the fore end of the cylinder thus was built up to a pressure of several hundred pounds per square inch. Part of this air passing through a connecting duct, actuated a small piston which, in turn, disconnected the handle and opened the valve to exhaust. With an open exhaust port the high pressure cushion returned the piston rapidly to the starting position. Proper adjustment of the exhaust port allowed the piston to come to rest at the rear of the cylinder without a bounce. Thus manual forward movement of the valve handle together with the pneumatic valve reversal mechanism completed the "ideal" punching stroke.

On Dec. 7, 1945, the improved Model 4 unit, incorporating all of the improvements noted above, was installed on a converter. This unit did a very good punching job and had less mechanical trouble

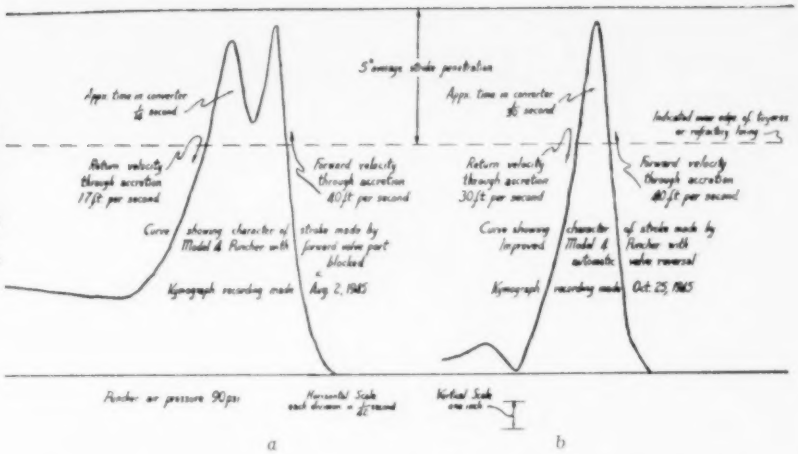
Appx. time in converter ½ second
Return velocity through accretion 17 ft per second
Forward velocity through accretion 40 ft per second
Curve showing character of Model 4 Puncher with forward valve port blocked
Kymograph recording made Aug. 2, 1945
Appx. time in converter ½ second
Return velocity through accretion 30 ft per second
Forward velocity through accretion 40 ft per second
Curve showing improved character of Model 4 automatic Puncher with valve reversal
Kymograph recording made Oct. 25, 1945
Puncher air pressure 90 psi
Horizontal Scale each division = 1/10 second
Vertical Scale one inch
a
b

Fig. 3—*a*. Puncher stroke utilizing full air cushion and manual reversal, August 1945. *b*. Ideal puncher stroke incorporating automatic valve reversal mechanism, October 1945.

than the previous units, so work was immediately commenced on rebuilding all the other punchers.

The punching performance of the rebuilt Model 4 units was satisfactory, and the converter operated without delay or trouble traceable to mechanical punching. Results now indicated that mechanical punching of *all* tuyeres on a converter could be performed successfully. However, before attempting to equip an entire converter with punching units, it was evident that many more mechanical improvements should be made.

The rebuilt Model 4 units were necessarily poor in mechanical construction, and breakages continued to occur. This was particularly true of the automatic valve reversal mechanism as the shock caused by the quick valve reversal was very severe. So, although a number of units continued to function satisfactorily, experimental shop and design work continued with the idea of developing something mechanically better. A new unit called Model 5 was completed and tested on a converter during October and November 1946. After some further test work it was decided to build a new model along similar lines, but with a larger power cylinder. A new unit—Model 6—was constructed, and after preliminary tests were completed it was tried out on a converter the latter part of December 1946. This unit was much lighter than Model 4, and included many improvements in mechanical construction. The cylinders were made of 3-in. ID brass tubing. The heads were cast so that they could be machined readily, and the valve ports were incorporated in the rear head. The cylinders and heads were held together by four tie rods somewhat similar to paving breaker construction.

Test-stand punching strokes along with practical operation on a converter made it possible to determine faulty operation or the weakness of any part more quickly. There was a gradual improvement in construction, also in the durability of parts, and in April 1947 it was decided that 50 units should be built by some outside manufacturer. Practically all of the work to date had been done in the plant shops, but experience indicated that a manufacturer

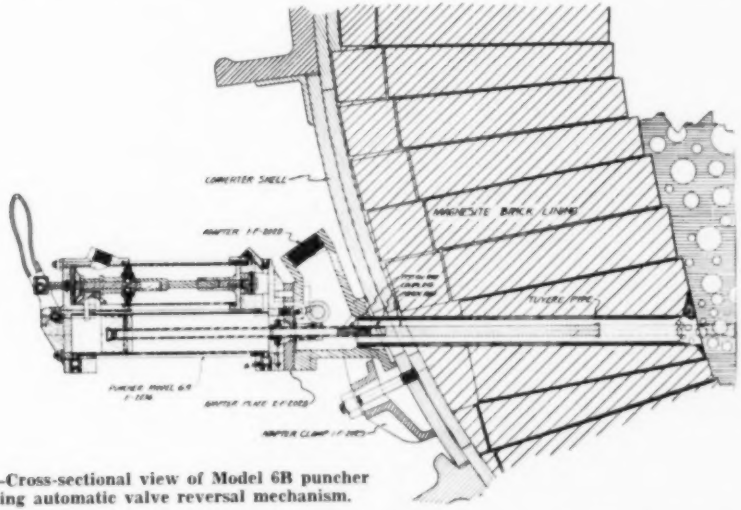

Fig. 4—Cross-sectional view of Model 6B puncher showing automatic valve reversal mechanism.

with the proper experience, equipment, and facilities could make a better machine.

The method of attaching the punchers to the adapters was not entirely satisfactory, so a new scheme was worked out. Necessary changes were made to one of the Model 6 punchers in order to attach this unit to a modified adapter by two side rods instead of by the stirrup arrangement used on the other punchers. Since the new method of attachment proved far superior, it was adopted and new drawings were made showing this change and other improvements in construction recently developed. The latest development included changes in the choice of materials, and the inclusion of synthetic rubber "O" ring seals throughout. Tests with "O" ring seals had demonstrated that, by their judicious use, puncher construction could be very much simplified and air leakage be reduced to a minimum. Drawings showing all of the latest developments were now prepared for a new unit to be called Model 6A. Two of these punchers were completed by a manufacturer late in December 1947.

In January 1948, one of the Model 6A punchers was placed on a converter where it operated along

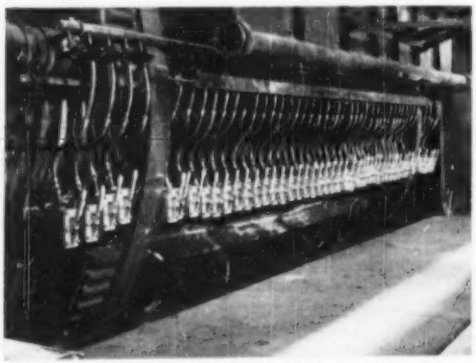

Fig. 5—Mechanical puncher installation placed in service on Aug. 23, 1948.

with the Model 6 punchers already in service. The new unit was adjusted for a forward stroke velocity of 45 fps, and operated for twelve weeks without a single failure of any kind. The other Model 6A unit was operated over 300,000 strokes (about the number of strokes it would make in 1000 days of service on a converter) on the test-stand in order to determine the durability of the various parts. Prolonged test-stand work indicated that minor changes should be made to two of the moving parts and that these should be made of a suitable alloy steel. Another set of drawings showing these and other minor changes was immediately prepared, and it was agreed that these drawings should be used for the manufacture of the 50 punchers previously ordered. The latest development was called Model 6B (fig. 4), and the manufacturer was instructed to complete 50 punchers as quickly as possible. At last, after all the years of development work, all the tuyeres of a converter were to be equipped with mechanical punchers.

The 50 Model 6B punchers arrived at McGill the latter part of June 1948. The necessary air connections were completed and the converter, with the complete mechanical puncher installation, was placed in service on the morning of Aug. 23, 1948 (fig. 5). It is believed that the charge of blister copper produced in this converter on this date was the first in the history of copper smelting to be successfully produced in a converter with the punching operation performed entirely by mechanical punchers.

The converter with the mechanical puncher installation has been in regular service, except when down for refractory repairs, from Aug. 23, 1948 to the present time. Very little mechanical trouble and no delays to converter operations have been experienced.

The mechanical puncher installation on this converter has been entirely successful and the disagreeable job of hand punching has been eliminated. Instead of avoiding this work, men now ask for and like the job of operating the mechanical punchers. One man can actually complete the 45 punching strokes in 30 sec.

In addition to the many problems and difficulties encountered in the development work, there are a number of other points, particularly as to operation, that should be explained. With the mechanical punchers, the punch rod remains inside the tuyere pipe; there is no blow back, no waste of blowing air, and no loss in pressure during the punching stroke. The punch rod is reversed and returns so swiftly that no slag or metal follows the tip back into the tuyere pipe. Thus the end of the tuyere pipe is kept clean, and it is not necessary to ream after completing a charge of copper.

With new refractory brickwork a punch rod long enough to penetrate 4 to 6 in. inside the converter is used. During operation, the end of the punch rod indicates the depth of penetration and a new rod of proper length is substituted as required. Punch rods often last for weeks, but in time become worn, burned, or bent. Long service is explained by the quick punching stroke which permits the tip to remain inside the converter only about 1/50 of a second. A worn or burned tip is re-formed, thus reclaiming the rod but making it a little shorter.

Resistance to air flow, resulting from the punch rod remaining in the tuyere pipe, was investigated early in the development work. Tests proved definitely then that it would not be increased materially if the area of the punching tip was not greater than the area of the annular ring between the tip and the inside of the tuyere pipe.

In the first campaign with the complete puncher installation, iron tubing with an inside diameter of 1.69 in. was used for tuyere pipes. With this size tuyere pipe, punch rod tips 1.19 in. in diam, which had a cross section half that of the pipe, were used. The copper production rate with this combination was 15 to 20 pct faster than hand punching for the same grade of matte. Air measurements made during the run confirmed the fact that blowing air input also increased about the same amount. In the next run, extra-strong pipe with an inside diameter of 1.9 in., and punch rod tips 1.31 in. in diam were used. With this combination it was found that blowing air input could be increased to any reasonable amount, the limitation being determined by slopping through the gas outlet. Perfecting operational techniques and experimentation with automatic puncher features has dictated use of the smaller tuyere for the time being, since the larger tuyere with attendant slopping is a problem in itself. Experience to date with the mechanical puncher installation has been so favorable that another converter is now being so equipped.

The Effect of Alloying Elements on the Plastic Properties of Aluminum Alloys

by J. E. Dorn, P. Pietrokowsky and T. E. Tietz

The amount of solid solution hardening in aluminum alloys was found to be dictated by two factors: the lattice strain, and the change in the mean number of free electrons per atom of the solid solution. To obtain this correlation it was necessary to assume that aluminum contributes two electrons per atom to the metallic bond.

WHEN the modern scientific method of analysis was first being formulated, Francis Bacon recorded in his "Essays" (circa 1600) that "an alloy . . . will make the purer but softer metal capable of longer life." During the intervening centuries voluminous data have been reported which demonstrate that the additions of alloying elements do in fact increase the hardness and strength of the pure metals. Nevertheless, the significant details of this problem on the unique effect of each element toward enhancing the mechanical properties of alloys only recently have been subjected to systematic scientific scrutiny. The major objective of this investigation is to determine how minor additions of alloying elements affect the plastic properties of polycrystalline aluminum alloys. By means of such studies it is hoped to provide not only data on the solution strengthening of aluminum alloys, but also a body of facts which will supplement the knowledge already available on the factors responsible for solution hardening in general.

J. E. DORN, Member AIME, is Professor of Metallurgy, P. PIETROKOWSKY, Junior Member, and T. E. TIETZ, Student Associate, are Research Engineers, University of California, Berkeley, Calif.

AIME Chicago Meeting, Oct. 1950.

TP 2888 E. Discussion (2 copies) may be sent to Transactions *AIME before Dec. 1, 1950. Manuscript received Dec. 20, 1949; revision received April 17, 1950.*

A review[1-10] and analysis[11] of the existing data on the effect of solute elements on the plastic properties of solid solutions reveal that our current knowledge on solid solution hardening is somewhat meager, inconsistent, and inconclusive. Many of the inconsistencies are undoubtedly attributable to the influence of unsuspected factors, such as purity; or uncontrolled factors, such as grain size, on the plastic properties of alloys. Nevertheless the following conclusions might be tentatively accepted:

1. Addition of solute elements invariably increases the yield strength, tensile strength, and hardness of the host element.

2. The rate of strain hardening, in general, increases with the concentration of the alloying element.

3. The strengthening effect in ternary alloys is the sum of the individual strengthening effects of the two solute elements as measured in their binary alloys.

4. The lattice strain is one factor that affects the strengthening of the alloy but it is not the only factor.

5. A second factor might be the difference in valence between the solute and solvent metals.

All of the available evidence is in complete agreement with the first conclusion; the remaining conclusions, however, are not in agreement with all of the published data, but, in each case, the major weight of the existing evidence favors these deductions.

Additional investigations will be required before most of these tentative conclusions can be accepted without reservation. In the following report an extensive investigation of the plastic properties of binary aluminum alloys is described. This work was undertaken in an attempt to shed more light on the general problem of solid solution hardening.

Materials for Test: Aluminum was selected as the solvent metal for the present investigation on the effect of solute elements on the plastic properties of alloys. This choice was made for several reasons: (1) There appears to be little fundamental data in the published literature on the effect of solute elements on the properties of high-purity aluminum alloys. In view of the ever increasing economic importance of aluminum, such data would be of basic interest to the metallurgists concerned with the development of new aluminum alloys. (2) Aluminum is thought to be only partially ionized in the metallic state[12] and consequently it might provide more complex relationships of the mechanical properties with the concentrations of the solute elements than more simple fully ionized solvents would reveal. (3) The data on aluminum alloys will provide a broader basis for correlations between the mechanical properties of metals in general and the concentration and atomic properties of the solute elements than is now available.

Some complications, however, attend the selection of aluminum: The solubility of the various elements in the alpha aluminum phase are quite restricted, and not always well known. Consequently, only dilute solid solutions are available for study. This, however, may be somewhat advantageous because the dilute solution laws presumably are simpler than those applying to concentrated solutions. In addition, strain-hardened pure aluminum is known to recover at atmospheric temperatures. Very likely its alloys exhibit slower recovery rates. Thus, the secondary factor of effect of alloying elements on recovery might complicate the data. Such compli-

cations, however, can be eliminated by testing at lower temperatures providing that the temperature is sufficiently low to prevent the supersaturated alloys from experiencing strain-aging or precipitation hardening effects. The wide interest in, and the industrial importance of, aluminum alloys prompted the selection of aluminum as the solvent metal for this study in spite of the difficulties that might be encountered.

The chemical compositions of the various alloys which were investigated are given in table I. Specimens for chemical analyses were taken from each melt just before pouring the ingot. All of the alloys except the Cu series were prepared from pure aluminum *A*; the Cu series of alloys were prepared at a later date from pure aluminum *B* stock. Analyses for the major alloying constituent were determined

Table I. Chemical Analyses of Alloys

Alloying Element	Atomic Pct	Atomic Number	Weight Pct of Residual Impurities				
			Si	Fe	Cu	Mg	Mn
Aluminum A	0	(13)	0.003	0.003	0.006	0.001	
Aluminum B	0	(13)	0.003	0.004	0.002	0.0006	0.001
Magnesium	0.554	12	0.003	0.003	0.007		
	1.097		0.004	0.004	0.007		
	1.617		0.003	0.004	0.006		
	3.228		0.003	0.004	0.007		
Copper	0.029	29	0.003	0.004		0.0006	0.001
	0.054		0.003	0.004		0.0007	0.001
	0.101		0.003	0.003		0.0006	0.001
	0.233		0.003	0.004		0.0006	0.001
Zinc	0.211	30	0.004	0.004	0.006	0.001	
	0.402		0.004	0.005	0.006	0.001	
	0.755		0.004	0.005	0.006	0.001	
	1.616		0.003	0.005	0.007	0.001	
Germanium	0.015	32	0.004	0.004	0.006	0.001	
	0.033		0.004	0.004	0.006	0.001	
	0.082		0.003	0.005	0.007	0.001	
	0.145		0.003	0.006	0.007	0.001	
Silver	0.025	47	0.003	0.005	0.006	0.001	
	0.053		0.003	0.005	0.006	0.001	
	0.100		0.003	0.005	0.007	0.001	
	0.194		0.003	0.006	0.007	0.001	
Cadmium	0.012	48	0.004	0.005	0.006	0.001	
	0.029		0.004	0.005	0.006	0.001	
	0.043		0.004	0.005	0.006	0.001	
	0.065		0.004	0.005	0.006	0.001	

by the usual chemical methods while the traces of impurities were evaluated by spectrochemical analyses. The authors express their sincere appreciation to the Aluminum Research Laboratories and their staff for preparing these alloys and making the chemical analyses.

The various heats were melted in a plumbago crucible in an electric resistor furnace. After the high-purity aluminum was melted it was fluxed for 2 min with chlorine gas after which the high-purity alloying elements were added and a second fluxing treatment with chlorine gas of about 1-min duration followed. Immediately after sampling for chemical analysis each melt was poured at a temperature of 1325°F into a 1.5x7x8 in. tilt mold ingot.

Each ingot was scalped and then preheated 6 hr at 920°F prior to rolling to a nominal thickness of 0.375 in. at 750°F. These slabs were then annealed for 2 hr at 650°F, cooled in air, and then cold-rolled to a thickness of 0.100 in.

Table II. Homogenization Treatment

Alloy	Time		Temperature
Pure aluminum	Homogeneous as received		
Magnesium	8 days	at	820°F
Copper	Homogeneous as received		
Zinc	16 hr	at	700°F
	5 hr	to	812°F
	8 days	at	812°F
Germanium	8 days	at	773°F
Silver	8 days	at	1,017°F
Cadmium	8 days	at	1,017°F

The original plan called for recrystallization treatment for each cold-rolled alloy at appropriate temperatures to obtain approximately the same grain size for each material. When small specimens of the various alloys were recrystallized and examined microscopically, it was noted that the etching was somewhat nonuniform, except for the pure aluminum and the copper series. Suspecting that this might be due to chemical heterogeneity, all of the alloys, which exhibited nonuniform etching characteristics, were given a homogenization treatment as outlined in table II. The various temperatures were selected with reference to the solidus temperature of each alloy. After the above treatments uniform etching was obtained and sharp X-ray back reflection lines resulted indicating good homogeneity.

Each alloy exhibited a somewhat different grain size after the above-mentioned homogenization treatment. Therefore, each homogenized alloy was cold-rolled from 0.100 to 0.070 in. thickness preceding the recrystallization treatment for uniform grain size. After a preliminary survey of recrystallization temperatures, the final schedule for recrystallization shown in table III was adopted. All recrystallization treatments were conducted in a salt

Table III. Recrystallization Treatment and Grain Size

Alloy	Atomic Pct	Time, Min	Temperature, °F	Grain Size Mean Diam Mm.
Aluminum A		45	925	0.53
Aluminum A		30	850	0.33
Aluminum A		10	800	0.21
Aluminum A		0.5	800	0.13
Aluminum A		2	775	0.11
Aluminum B		15	800	0.26
Magnesium	0.554	10	800	0.25
	1.097	10	800	0.28
	1.617	10	800	0.26
	3.228	10	800	0.27
Copper	0.029	90	800	0.29
	0.054	75	800	0.29
	0.101	50	800	0.29
	0.233	60	800	0.30
Zinc	0.211	5	720	0.26
	0.402	10	720	0.27
	0.755	5	720	0.26
	1.616	4	720	0.26
Germanium	0.015	30	700	0.27
	0.033	5	700	0.26
	0.082	30	700	0.27
	0.145	5	700	0.26
Silver	0.025	30	700	0.31
	0.053	30	700	0.29
	0.100	30	700	0.29
	0.194	5	850	0.29
Cadmium	0.012	20	750	0.29
	0.029	5	900	0.26
	0.043	30	850	0.31
	0.065	5	850	0.31

bath furnace and the specimens were cooled in air. Grain size measurements were made by taking a linear count of the number of grains across the width of the specimen at 100 magnification. The average of three counts was taken as the grain size.

Testing Procedures: The tensile specimens were carefully machined from 0.070 in. thick sheet with their axes in the rolling direction. The reduced section of the specimen was 3 in. long and 0.250 in. wide; the central 2.00 in. of the reduced section was used as the gauge length. After machining, the specimens were given the appropriate recrystallization treatment for uniform grain size, and the

width and thickness of each specimen was gauged with a hand micrometer sensitive to ±0.0001 of an inch.

The load was measured using a proving ring equipped with a dial indicator, and was sensitive to ±½ lb. A rack and pinion strain gauge having a 2-in. gauge length was used to measure elongations. Periodic calibrations showed this gauge to yield strains accurate to within ±0.001 in. All tests were conducted at a true strain rate of approximately 9.5×10^{-4} per sec.

The tensile tests at 78°K were conducted in a special container with the specimen in direct contact with liquid nitrogen. The 116°K test temperature was obtained with the specimen in a "freon 12" bath. Liquid nitrogen was circulated through a coil of copper tubing in the freon bath. Solid freon formed on the coils and was allowed to melt during the tensile test, maintaining constant test temperature. Tests at 194°K were conducted with the specimen in a bath of acetone and solid CO_2, a screen restricted the solid CO_2 particles from direct contact with the specimen and extensometer. The tensile tests at approximately 295°K were conducted in the atmosphere.

X-Ray Study of Alloys: The effects of preferred orientation upon the properties of metals have been extensively investigated. It is well known that such properties as yield strength, tensile strength, and elongation of polycrystalline alloys are dependent upon the degree of preferential crystallographic orientation. The possibility of the presence of different degrees of preferred orientation in the tensile test specimens of the various alloys of this study was recognized and an X-ray study of all the aluminum alloys was conducted. The tensile specimens that were tested at liquid nitrogen temperature were used for this investigation because they showed the greatest strain hardening and might, therefore, have developed the most pronounced preferred orientation of grains.

After each tensile test at liquid nitrogen temperature had been completed, a back reflection X-ray picture of the specimen was taken. Because of the relatively large grain size of the tensile specimens it was necessary to place the specimens on a linear oscillator to obtain Debye-Scherrer rings on the back reflection pictures. Only two exposures of each specimen were made. In one, the X-ray beam of characteristic copper radiation was directed normal to the rolling plane whereas in the other it was directed normal to the edge of the specimen. All of the alloys excepting those containing 0.029 and 0.101 at. pct Cu, 0.043 and 0.065 at. pct Cd, and 0.015 at. pct Ge indicated random grain orientation in this state. In the cases of the few exceptions the degree of preferred grain orientation was so slight that it was considered to be negligible.

Precision Lattice Constants: One factor that is known to affect the amount of solid solution strengthening is the local lattice strain caused by the difference in the atomic radii of the host and foreign atoms. No exact method has yet been devised for determining the local lattice strains. As a first approximation the local lattice strain might be estimated by applying Vegard's law to the known data on the atomic radii of the elements. Two possible sources of error, however, might be introduced by this procedure. First, Vegard's law is known to have only approximate validity and, second, the atomic radius of a solute element might be a function of its environment in the lattice of the host element and thus differ from the radius of the element in its native state.[18] It appeared to be desirable, therefore, to determine the change in lattice constant for the alloys under investigation directly, in order to measure the lattice strains which they induce. Of course, this procedure provides a measure of the mean lattice strain rather than the local lattice strain.

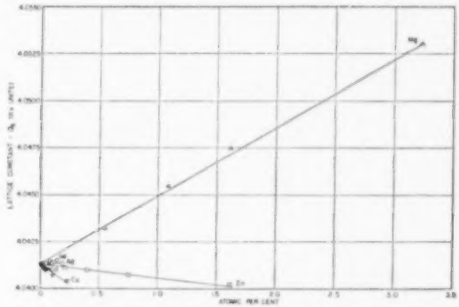

Fig. 1—Effect of alloying elements on the lattice constant of aluminum.

But it is expected that in binary alloys the local lattice strains are related in some simple manner to the mean lattice strains. Consequently, it might be justifiable to use the mean lattice strains in lieu of the local strains for the comparisons planned here.

A 10 cm diam symmetrical precision focusing camera having a Bragg angle range from 54.7° to 86.4° was used to determine the lattice parameters of the various alloys. The X-ray beam consisted of the unfiltered radiation from a copper target source powered with an XRD unit.

Powders for X-ray specimens were prepared from the completely homogenized alloy sheets by filing. After particles larger than a 200 mesh were removed by screening, the powder was sealed in pyrex tubes and annealed for 1½ hr at 485°F for relief of stresses. Spectrographic analyses of the powdered

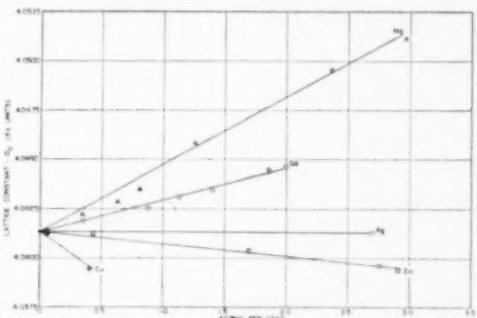

Fig. 2—Effect of alloying elements on the lattice constant of aluminum.
(Aron and Hume-Rothery.[20])

specimens before and after annealing showed that no contamination by silicon occurred during the annealing.

Films for the entire series of alloys of one element were cut from the same sheet of X-ray film in consecutive order. Corrections for uniform film shrinkage were made by the utilization of calibration lines which were printed on all films prior to their ex-

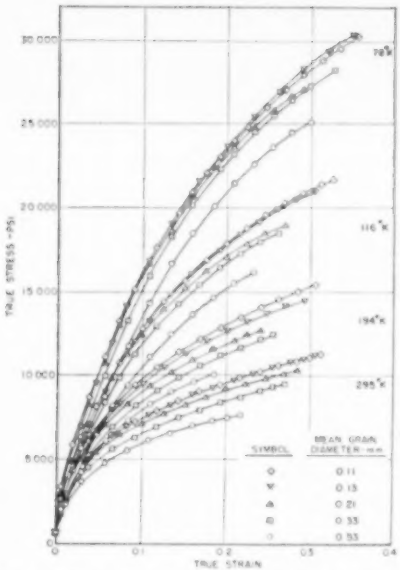

Fig. 3—Effect of grain size on the true stress-true strain curve of pure aluminum *A* at four test temperatures.

(Strain rate, 9.5×10^{-4} per sec.)

posure in the 10 cm focusing camera. Furthermore, films from each series of four alloys of the same alloying element were developed simultaneously.

Films were read with the aid of a low power traveling microscope which was actuated by a lead screw and calibrated drum mechanism. Errors in the lead screw pitch were measured with a Bureau of Standards calibrated meter bar, B.S. No. 4371. Consistent measurements of one thousandth of a Bragg degree were readily obtained. To keep the precision lattice constant results consistent with those reported in the literature, the wave length of the copper radiation used for calculations was evaluated in kx units. In order to determine the average temperature for each exposure, a thermocouple was placed just above the specimen in the focusing camera. The average variation in temperature during any one exposure was about $\pm \frac{1}{2}$ °C. All lattice constants were corrected to a standard temperature, 25°C, taking 23.1×10^{-6} to be the value of the linear coefficient of expansion for all of the aluminum alloys; according to Hume-Rothery,[19] the difference in the coefficient of expansion among the various aluminum alloys is negligible if the temperature correction is less than 10°C. No corrections for the index of refraction were made. Extrapolation to a Bragg angle of 90° was accomplished by use of the method described by Nelson and Riley.[20]

Table IV. Precision Lattice Constants in kx Units Corrected to 25°C

Alloy	Atomic Pct	Lattice Constant a_0
Aluminum A		4.0413(0)
Aluminum B		4.0412(6)
Magnesium	0.554	4.0432(6)
	1.097	4.0454(5)
	1.617	4.0474(9)
	3.228	4.0530(6)
Copper	0.029	4.0411(0)
	0.054	4.0408(7)
	0.101	4.0406(9)
	0.253	4.0405(8)
Zinc	0.211	4.0411(2)
	0.402	4.0409(8)
	0.755	4.0407(1)
	1.516	4.0402(0)
Germanium	0.015	4.0413(0)
	0.035	4.0413(5)
	0.092	4.0413(9)
	0.145	4.0414(9)
Silver	0.025	4.0412(8)
	0.053	4.0412(9)
	0.100	4.0413(1)
	0.194	4.0413(1)
Cadmium	0.012	4.0411(6)
	0.029	4.0411(0)
	0.043	4.0410(6)
	0.053	4.0410(6)

The precision lattice constants for all of the alloys that were studied in this investigation are presented in table IV; included in this table are the lattice constants for the two different parent metals used in alloying, namely, pure aluminum *A* and aluminum *B*. The effect of concentration of the alloying elements on the lattice parameters of aluminum alloys is shown in fig. 1.

A comparison between the results of Axon and Hume-Rothery,[19] which are reproduced in fig. 2, and the data of this investigation show in general a fairly good correlation, in spite of the slight differences in purity of the host aluminum that was used in the two investigations.

The data recorded here and those presented by Axon and Hume-Rothery for the Al-Ag, Al-Zn, and Al-Ge systems show excellent agreement; furthermore, the lattice parameters for each of these alloy systems is a linear function of the atomic percent of the solute element. Whereas Axon and Hume-Rothery suggest that the lattice parameter for the Al-Cu alloys increases linearly with the atomic percent of copper and that the Al-Mg system yields a curvilinear relationship, the data recorded here indicate that the Al-Cu system gives a curvilinear relationship, while the Al-Mg system again gives a linear relationship. In view of the rather careful experimental determination of the lattice constants in both investigations and particularly in view of the small range of concentrations of alloying elements which were included in this analysis, it appears as if the nonlinear data are accidental and the relationship between lattice strain and atomic percentage for each alloy series is truly linear over the range of conditions investigated here.

Table V. Change in Lattice Parameter for One Atomic Percent of the Alloying Element In kx Units

Element	Δa Axon and Hume-Rothery	Δa Present Investigation
Magnesium	+ 0.00345	+ 0.00363
Copper	—0.00488	—0.00495
Zinc	—0.000605	—0.00068
Germanium	+ 0.00166	+ 0.00138
Silver	0.00000	0.00000
Cadmium		—0.00349

The results for the Al-Cd alloys indicate that the solubility limit was exceeded in the two highest concentrations of this series. No additional X-ray lines for cadmium were observed in the diffraction pictures and no cadmium phase was detected upon metallographic examination. But these techniques might not have been sensitive enough for the detection of the small amount of the precipitated cadmium phase. The suspected solubility limit of cadmium in aluminum, as determined from the present

lattice constant data, however, agrees well with the best available data reported by Mondolfo[21] for the Al-Cd system. Consequently, the data on the plastic properties for the two highest concentrations of cadmium must be deleted from comparisons of solid solution hardening.

For purposes of future reference the change in lattice parameter for 1 at. pct of the various alloying elements is given in table V. These data were evaluated using the best straight line through the experimental points.

Experimental Results: The plastic properties of polycrystalline alloys are known to depend not only on the concentration of the various alloying elements but also on their grain size. Although Lacy and Gensamer[22] have shown that the plastic properties of binary ferrites are rather insensitive to nominal variations in grain size, Frye and Hume-Rothery[23] indicated that the hardness of silver alloys is sensitive to changes in grain size. Inasmuch as aluminum, like silver, exhibits a crystallographically face-centered cubic structure, it was expected that its plastic properties might also be sensitive to rather small variations in grain size. In order to determine the effect of grain size on the plastic properties of aluminum alloys, the data presented in fig. 3 were obtained. Pure aluminum *A* was selected for this purpose and was heat treated in accordance with the schedule shown in table III to obtain the various grain sizes. It is immediately evident that the plastic properties of pure aluminum are very sensitive to grain size over the range of grain size, strain rate, and temperature which was investigated. Obviously not only the initial flow stress but also the rate of strain hardening increases with decreasing grain size. The final point on each graph represents the point at which the tensile specimen first experienced necking. Thus decreasing grain size also results in greater uniform strains in tension. Furthermore, the effect of decreasing grain size on increasing the flow stress of aluminum alloys becomes most pronounced at the lowest test temperature.

Hollomon[24] has shown that the empirical relationship:

$$\sigma = k E^n \qquad [1]$$

where: σ=flow stress
E=true plastic strain
k=flow stress at unit strain
n=work hardening index

is quite valid for many steels and also some nonferrous alloys. When this relationship is valid the plastic properties of materials can be simply related to the two parameters k and n. Lacy and Gensamer used this relationship advantageously in their investigations on binary ferrites. It was the original plan of the present authors to evaluate the effect of alloying elements in aluminum with their effects on k and n of eq 1. Unfortunately, as shown in fig. 4, this simple relationship is not valid for high purity aluminum. According to eq 1 the logarithm of the stress should be a linear function of the logarithm of the strain. As shown in fig. 4, however, the logarithm of the stress is actually a curvilinear function of the logarithm of the strain. Consequently this simple approach to the evaluation of the plastic properties of aluminum alloys had to be discarded. Correlation with other empirical relations were attempted but none of them agreed

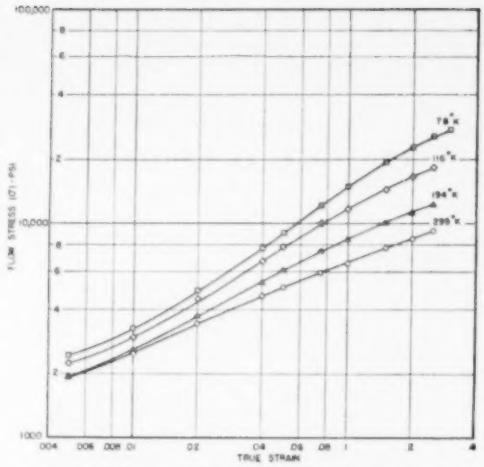

Fig. 4—Failure of the relationship $\sigma = kE^n$ for pure aluminum *A*.

well enough with the data to warrant their use in this investigation. Consequently, it became necessary to use the experimentally determined true stress-true strain curves directly as a basis for comparing the effects of the various alloying elements on the plastic properties of aluminum alloys.

The stress-strain curves for pure aluminum and for four compositions of each of the six different alloying elements were determined at four temperatures each. The stress-strain curves for the aluminum-copper alloys at the four test temperatures are shown in fig. 5. Before any elaborate analyses were attempted on the data for the various alloy systems, it was considered advisable to ascertain

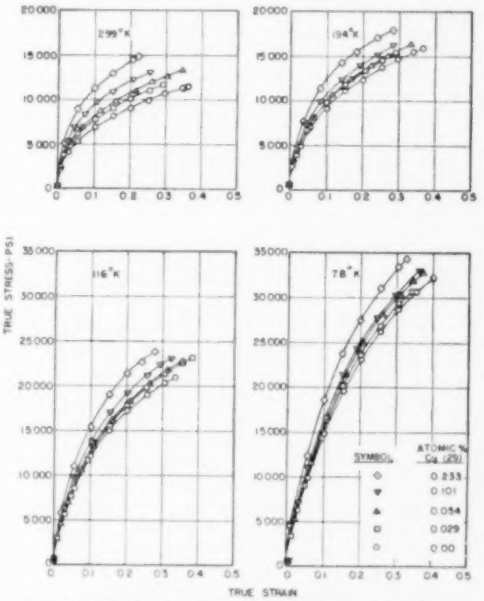

Fig. 5—Effect of copper on the true stress-true strain curve of aluminum at four test temperatures.

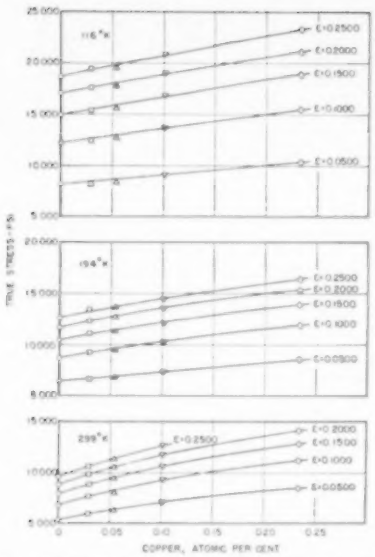

Fig. 6—Effect of atomic percent copper (29) on the flow stress of aluminum for various strains.

how thoroughly self-consistent these data were among each alloy system over the range of temperatures which were investigated.

The good internal self-consistency of these data was revealed by cross-plotting the flow stress as a function of the atomic percent of the added element for a series of strains. The values used in these plots were interpolated from the original true stress-true strain data. Since the average grain diameter of the alloy specimens was about 0.28 mm, the data used in these plots for pure aluminum were also taken for the same grain size. Representative cross-plots of this type are shown in fig. 6 for the aluminum-copper alloys. Inasmuch as the Al-Cu series were prepared from pure aluminum *B*, a slight additive correction was applied to the Al-Cu series in order

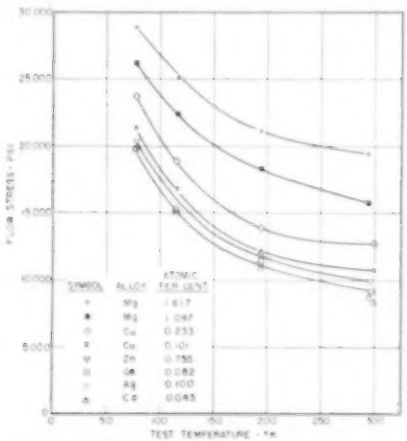

Fig. 7—Effect of test temperature on the flow stress of various aluminum alloys for a true strain of 0.150.

to permit direct comparisons with the remaining alloy systems.

In order to ascertain whether the various alloys respond in an analogous fashion to changes in temperature, the flow stress for a strain of 0.150 was plotted as a function of the test temperature for each alloy. In fig. 7 are shown typical plots of this kind for various concentrations of the different alloys. These curves reveal that the same qualitative trends of solution hardening are observed independent of the test temperature.

This uniformity of data suggests that none of the alloys which were tested exhibited any anomalous behavior which could be attributable to possibilities of precipitation hardening, strain aging, or anomalous recovery. If these phenomena are present, they do not appear to alter the relative order of the alloys with respect to their effects on solid solution strengthening.

Discussion of Results: The cross-plots obtained from the true stress-true strain data revealed that the flow stress of binary aluminum alloys invariably increased with increasing atomic percentages of the solute elements. The effect of alloying elements was most pronounced at the lower concentrations and became less effective for the higher percentages of the alloying elements. Furthermore, alloying additions not only increased the yield strengths of metals but also simultaneously induced greater rates of strain hardening.

The uniform strain up to the point of inception of necking in the tension tests exhibited appreciable scatter. These data, however, indicated that the strains to necking invariably increase with decreas-

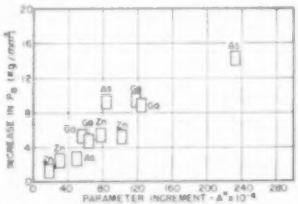

Fig. 8—Effect of lattice strains on the Meyer's hardness number of copper alloys.
(Frye and Caum.[17])

ing test temperatures. On the other hand, the effect of alloying additions on the strain to necking is minor, being only slightly greater than the experimental scatter. In general, increasing concentrations of alloying elements appeared to reduce the uniform strain; but, probably due to scatter in these data, a few cases existed which showed contradictory trends.

It would indeed be interesting to ascertain quantitatively the effect of each alloying element on the flow stress of its matrix metal as a function of temperature. Unfortunately the theoretical bases for such comparisons are not available and all comparisons that might be made at present are complicated by the effect of temperature of straining on the rate of strain hardening.[23] Nevertheless, a qualitative picture of this effect can be deduced from the data reported here.

In general, straining at a lower temperature is known to induce a greater amount of strain hardening than that introduced by the same strain at a higher temperature. In spite of this fact, the increase in flow stress upon alloying, as measured at

a fixed strain, is less at the lower test temperature. Consequently, the influence of solute elements on solution strengthening increases, without known exception, with increasing temperature of test.

Lattice strains are known to be one of the factors that is responsible for solid solution strengthening. Some of the earlier data on the effect of alloying elements on solution hardening seem to imply that other factors might also be effective in causing solution hardening. The data obtained in this investigation for the Al-Ag alloys reveal conclusively that this is indeed so. In spite of the fact that silver induces practically no lattice strain, it nevertheless causes appreciable solid solution strengthening.

Some existing data suggest that a second factor is associated with the atomic period of the solute elements in such a way that the solution strengthening is dependent solely on the lattice strain for all solute elements having the same ionic core, independent of their valence, whereas elements from other periods exhibit appropriately different relationships between solution hardening and lattice strain.[10] This viewpoint is unacceptable to the present authors; it is indeed more likely that the second factor is actually associated with the conditions of metallic bonding as evidenced by the difference in valency of the host and foreign elements. At least

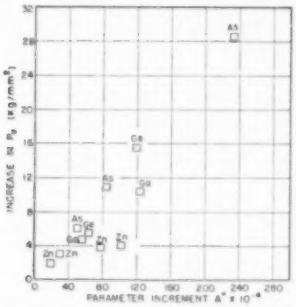

Fig. 9—Effect of lattice strains on the Meyer's ultimate hardness number of copper alloys.
(Frye and Caum.[10])

this appears to be a more logical assumption and in addition it has partial confirmation when some of the best currently available data on solution hardening are correlated with the valence of the solute elements.

Frye and Caum[10] determined the effect of various solute elements of the third period of the Periodic Table of Elements on the Meyer's Hardness Number of copper alloys. The experimental values of Meyer's Hardness Numbers, P_s and P_n, for the alloys that were investigated are given as functions of the change in lattice parameter in figs. 8 and 9 where

$$P_s = \frac{4a}{\pi} \text{ (for impressions of unit diameter)}$$

$$P_n = \frac{4aD^{n-2}}{\pi} \text{ (for impressions equal to diameter of penetrator)}$$

a = load required to make an impression of unit diameter (1 mm)
n = a measure of the rate of strain hardening
D = diameter of the impressed sphere (4 mm).

It is immediately apparent that the amount of solution hardening is not solely a function of the lattice strain.

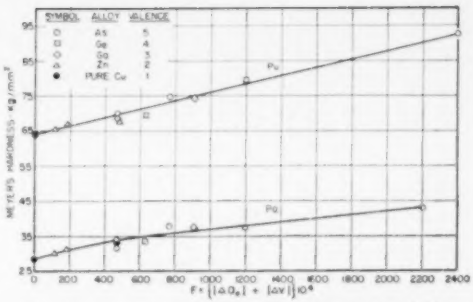

Fig. 10—Meyer's hardness vs. a composite strain hardening function for the data of Frye and Caum.

The results on solid solution strengthening of aluminum alloys suggested to the authors that solid solution hardening depends on both the mean lattice strain and the change in the average number of electrons per atom upon the addition of solute elements. If the change in the average number of electrons is small, as is the case for dilute solutions, the effect of lattice strain and change in the number of electrons should be additive. Thus, the hardness of alloys would then depend on the function

$$F = |\Delta a| + k|\Delta v|$$

where

Δa = the change in lattice constant

$$\Delta v = \frac{\text{Atomic Percent Solute}}{100} \times (\text{Valence of Solute} - \text{Valence of Solvent}).$$

The Meyer's Hardness Numbers obtained by Frye and Caum[10] are plotted as a function of F in fig. 10.

The value of $k=1$ was selected to provide good agreement between the data. For $k > 1.5$ or < 0.5 considerably greater scatter was obtained. The rather excellent correlation between the hardness as a function of lattice strain and valence electrons is further supported by the results to be described in the main text of this report on the solution strengthening of aluminum alloys.

If two factors affect the plastic properties of alloys, it is quite possible that these factors will individually have unique effects on the flow stress. It is conceivable that one factor, for example, might exhibit its major affect on the yield strength and only

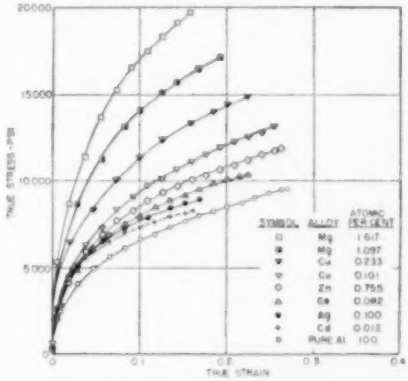

Fig. 11—Stress-strain curves for various aluminum alloys at 295°K.

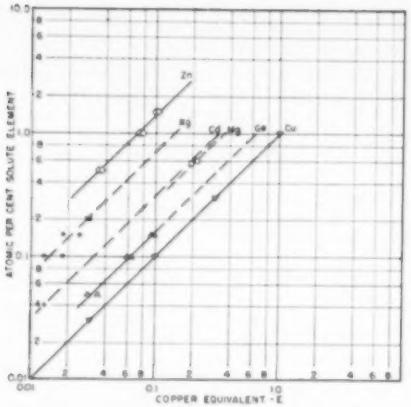

Fig. 12—Strain hardening equivalency of the various solute elements as based on the strain hardening of the aluminum-copper alloys.

slightly modify the rate of strain hardening whereas the second factor might, in contrary fashion, cause a pronounced increase in the rate of strain hardening but only affect the yield strength in a minor way. If this were so, various combinations of initial flow stress and rates of strain hardening would be achievable by appropriate selection of alloying elements. In fact each element might exhibit some unique effect on the plastic properties. In order to test this concept the general shapes of the stress-strain curves were compared in order to ascertain whether or not they are similar. A typical plot for this comparison is shown in fig. 11. In general the stress-strain curves for the various aluminum alloys appear to be members of a family of curves, suggesting that the effects of the various elements might be analogous. Only two minor exceptions are noticeable: Alloying with Cd and, to a lesser extent, alloying with Ag appear to yield aluminum alloys that have slightly lower rates of strain hardening than is obtained in alloys of the remaining elements under consideration here. Since no change in lattice parameter of aluminum is detectable upon alloying with silver, it is reasonable to suspect that the solution hardening due to silver is attributable to a valency effect. Other alloying elements such as Cu, Ge, Mg, and Zn do not appear to induce unique plastic properties, whereas Cd, which has the same valence as Zn and Mg, appears to have a lesser rate of strain hardening than the remaining elements that were studied. Consequently, there is no basis at present for attributing the lesser rate of strain hardening of the Ag and Cd alloys to a valency effect. A possible cause of the slightly smaller rates of strain hardening of the Ag and Cd alloys is revealed by reviewing the grain sizes shown in table III. In general the grain sizes used in this investigation for the Ag and Cd alloys were slightly greater than those of the other alloying elements. As shown in fig. 3, the rate of strain hardening is lower for larger grain sizes. Consequently, the smaller rates of strain hardening for the Ag and Cd series of alloys probably are partly attributable to grain size differences.

Table VI. Flow Stress Values for Aluminum Alloys Containing Equivalent Atomic Percentages of Various Solute Elements

Atomic Percent	True Strain				
	0.05	0.10	0.15	0.20	0.25
			295°K		
0.390 pct Zn	6,000	7,600	8,750	9,800	1,070
0.194 pct Ag	6,000	7,650	8,700	9,500	
0.028 pct Cu	5,980	7,650	8,850	9,800	1,075
0.043 pct Ge	6,250	7,800	8,700	9,700	1,050
0.075 pct Mg	6,000	7,800	8,800	9,800	
			194°K		
0.390 pct Zn	7,100	9,600	11,400	12,800	13,400
0.194 pct Ag	7,500	10,000	11,400		
0.028 pct Cu	6,700	9,200	10,800	12,400	13,200
0.043 pct Ge	7,200	9,600	11,100	12,400	13,400
0.075 pct Mg	6,700	9,400	11,000	12,400	
			111°K		
0.390 pct Zn	8,500	12,600	15,500	17,600	19,300
0.194 pct Ag	9,000	12,700	15,300	17,250	
0.028 pct Cu	8,500	12,600	15,500	17,700	19,300
0.043 pct Ge	8,800	12,900	15,500	17,400	18,900
0.075 pct Mg	8,500	13,000	15,800	18,000	19,600
			18°K		
0.390 pct Zn	9,600	15,700	20,000	23,400	26,200
0.194 pct Ag	10,200	15,500	20,000	23,300	25,700
0.028 pct Cu	9,600	15,700	20,000	23,300	26,100
0.043 pct Ge	10,000	15,700	19,800	23,100	25,700
0.075 pct Mg	9,700	15,700	20,000	23,800	26,200

In order to illustrate the approximate equivalent characteristics of the various alloys, the stress-strain data shown in table VI were assembled. These data were taken directly from cross-plots of flow stress as a function of atomic percent added element. The data for the Cd alloy could not be included in this series because the flow stress for the highest concentration of Cd that was investigated fell below the values given in table VI.

The data of table VI reveal that binary aluminum alloys containing the recorded atomic percentages of the various solute elements, have almost identical plastic properties. Although the alloy containing 0.194 at. pct Ag strain hardens slightly less rapidly than most of the remaining equivalent alloys, its plastic properties are not drastically different from those of the other alloys. The various compositions of binary aluminum alloys that are recorded in table VI, therefore, represent equivalent compositions insofar as they cause equal solid solution strengthening over wide ranges of test temperatures and strains.

Cross-plots of flow stress vs. atomic percent added element were used to determine the atomic percentage of copper required to give the same stress-strain curve as each of the alloys. These data were plotted in fig. 12 in terms of the atomic percent of the alloy as a function of its copper equivalent, E. To illustrate the significance of fig. 12 consider the highest datum for the Zn alloys. Comparison of the stress-strain data of the Zn alloys with the Cu alloys revealed that an alloy containing about 1.6 at. pct Zn gave identical stress-strain curves at each temperature investigated as was obtained for an alloy containing about 0.1 at. pct copper. On this basis the equivalent E for copper is equal to its atomic percent and consequently is represented by a 45° line on the log-log plot of fig. 12. The various data for Zn and Ge also gave 45° lines illustrating that for these alloys, the linear relationship

$$E = K \times (\text{atomic percent}) \qquad [2]$$

is valid; K being defined as the copper equivalent for 1 at. pct of the various solute elements. Only one datum each could be obtained for the Cd and Mg series of alloys. Inasmuch as Zn and Ge yielded a

linear relationship between their atomic percentages and the copper equivalent, and because over the small ranges of variables under consideration almost any functional relationship will become linear, straight lines at 45° to the coordinate axes were also drawn for these elements. The conclusive validity for this procedure will be substantiated later.

It was not possible to obtain highly accurate equivalent values for the Ag alloys as shown by the scatter in these data due to the fact that they work hardened slightly less rapidly than the remaining alloys. Nevertheless a best straight line at 45° to the coordinate axes was also drawn through the scatter of the Ag alloy data.

Reference to fig. 12 reveals that for equal atomic percentages of the alloying elements, copper causes the greatest solid solution strengthening, and that the remaining elements Ge, Mg, Cd, Ag and Zn are successively less effective for solid solution strengthening. The value of K, which is the copper equivalent for 1 at. pct of the various elements, is given in table VII. In addition the chemical valence and the change in lattice parameter are also recorded for future reference.

Table VII. Equivalent Concentrations for One Atomic Percent of the Solute Elements

Solute Element	K	Δa in kx units per 1 At. Pct	Atomic Number	Valence
Copper	1.00	−0.00495	29	1
Germanium	0.64	+0.00138	32	4
Magnesium	0.37	+0.00383	12	2
Cadmium	0.33	−0.00349	48	2
Silver	0.15	0.00000	47	1
Zinc	0.071	−0.00068	30	2

A preliminary survey of the data of table VII reveals that K is not a simple function of Δa per 1 at. pct of the element, nor is it exclusively a simple function of the valence of the addition element. It would indeed be gratifying now to be able to ascertain what factors affect the K values.

Mott and Nabarro[3] have stated recently that the yield stress for solid solutions is given by the relationship

$$\sigma = G\,\delta^{2}\,[N^{1/3}\,(\ln N)^{1}] \qquad [3]$$

where

G = shear modulus of elasticity

$\delta = \frac{1}{a}\,\frac{\Delta a}{\Delta N}$

a = lattice constant

$\Delta a/\Delta N$ = the change in lattice constant per mol of the alloying element.

This equation was derived on the basis of the dislocation theory appropriate for single crystals of dilute alloys in which local lattice strains might inhibit the migration of a dislocation. A few checks on the accuracy of this theory were made with the present data on aluminum alloys in spite of the fact that the theory was formulated for single crystals. Unfortunately, this theory is not in qualitative agreement with the present data. Perhaps the major reason for the failure of this theory is associated with the fact that it was predicated on the hypothesis that the amount of solution hardening is a quadratic function of the lattice strain only and that other factors such as valence are not significant factors in causing solid solution hardening.

In view of the failure of the best theories that are available for correlating the effect of alloying elements on solution hardening, it now becomes necessary to deduce what factors are significant directly from the experimental data. Toward this objective the values of K, the equivalent per atomic percent of the alloying elements, were plotted as a function of the absolute value of the change in lattice parameter per atomic percent solute, as shown in fig. 13. It is again immediately apparent that the values are not a simple function of the lattice strain.

It appeared to be logical to assume that the K values depended not only on lattice strain but also on the valence of the solute atoms. On the basis of this assumption, all elements contributing the same number of electrons to the binding of the metals should exhibit the same K values at equal lattice strains. Since the solutions under study here were dilute solutions and since the equivalent percentage of each alloy system increased linearly with the atomic percent of the solute atom, it was reasonable to assume that K for all elements of the same valence was also a linear function of Δa per atomic percent of the solute. A straight line was therefore drawn through the data for the elements having a valence of two, namely, Zn, Mg, and Cd, as shown in fig. 13. It is significant to note that this line also passes through the origin. Another straight line was then drawn through the data for the elements having a valence of one, namely, Ag and Cu. The straight line for the monovalent elements not only fails to pass through the origin of the coordinate system but it also has a greater slope than that for the bivalent elements. This suggests that the line for the quadrivalent elements, of which Ge is the only representative element that was investigated, also should have a different slope and different intercept at $\Delta a = 0$, from the other elements, as indicated by the broken line.

Inasmuch as the lattice strain upon alloying aluminum with silver is negligible, the solution hardening caused by silver is probably attributable to the difference in valence between silver and aluminum. If then the value of K at $\Delta a = 0$ depends on the difference in valence between the host and solute elements, those elements having $K = 0$ at $\Delta a = 0$ apparently have the same valence as aluminum. Consequently, the data of fig. 13 suggest that alu-

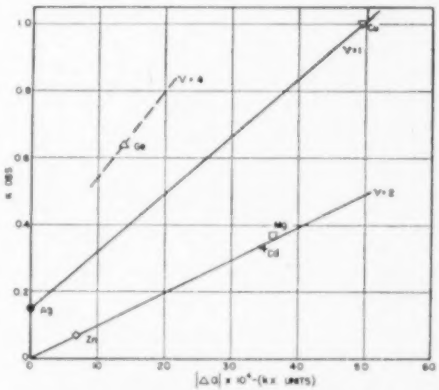

Fig. 13—Variation of the observed values of K with the absolute value of the change in lattice parameter for 1 at. pct of solute element.

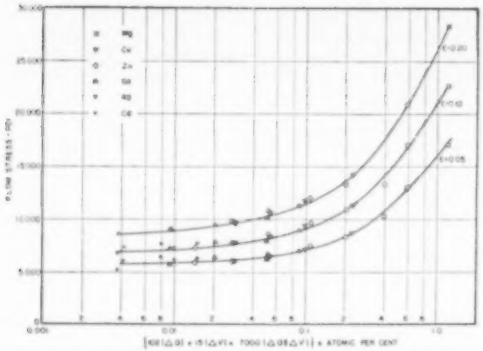

Fig. 14—Variation of flow stress with $K \times$ at. pct for strains of $E = 0.05$, 0.10, and 0.20 at 295°K.

minum is bivalent in the metallic state since the line for the bivalent elements passes through the origin of the K-Δa plot.

The choice of a valence of two for aluminum may at first be somewhat disconcerting. The agreement and order which will be shown to result from this choice for correlating the present data on solid solution hardening will strengthen the utility if not the actual validity of this choice. But for the present it appears to be desirable to reflect on the possible existence of other data that also infer that the valence of aluminum in the metallic state might be anomalous. It is well known that the melting temperatures of the metallic elements in any normal period of the periodic table increase rather uniformly with their atomic number. This normal increase, however, is not observed when considering the melting temperatures of Mg (12) and Al (13).

Table VIII. Comparisons of Observed and Calculated K Values

Alloy	K Obs.	K Calc.
Copper	1.00	1.00
Germanium	0.64	0.63
Magnesium	0.37	0.37
Cadmium	0.33	0.36
Silver	0.15	0.15
Zinc	0.071	0.069

As a matter of fact the melting temperature for aluminum is practically the same as that for magnesium suggesting that aluminum also has a valence of about two in the metallic state. Secondly, the atomic radii of the metallic elements decrease with increasing atomic number. The difference between the atomic radii of Mg (12) and Al (13), however, is less than normal for a change in valence from two to three. Here again the experimental evidence suggests that aluminum is ionized only partially in the metallic state. Such observations as these support the contention that aluminum might actually contribute about two rather than three electrons to the metallic bond.*

* After the draft of this report had been completed the author's attention was directed to an article by N. V. Ageev and L. N. Guseva published in *Bull. Acad. Sci. U.S.S.R., Classe sci. chim.* (1945) 289-296, concerning the "Distribution of the Electron Density in Metallic Aluminum". An abstract of this article reveals that "Comparison between the experimental (structure factor) curves and the theoretical curves drawn for Al^{+} and Al^{+++} leads to the conclusion that in the metal crystal lattice, Al is present as approximately bivalent ions".

Assuming that aluminum contributes only two valence electrons to the metallic bond, the change in free electron concentration per atom for each atomic percent of a solute atom of valence v is given by

$$\Delta v = \frac{v-2}{100} \qquad [4]$$

Since electronic hardening occurs when Δv is negative, as in the case of Ag, K is probably an even powered function of Δv. But in view of the small changes in the average number of electrons per atom it will be appropriate to assume that K is not only a linear function of $|\Delta a|$ but also a linear function of $|\Delta v|$.

Consequently, we assume that

$$K = k_1 |\Delta a| + k_2 |\Delta v| + k_3 |\Delta a||\Delta v| \qquad [5]$$

Using the experimentally determined K values for pure aluminum, magnesium, silver and copper to evaluate the constants k_1, k_2, and k_3 we find that

$$K = 102 |\Delta a| + 15 |\Delta v| + 7{,}000 |\Delta a||\Delta v| \qquad [6]$$

To check the nominal validity of this approach, the values of K for the remaining elements were calculated as shown in table VIII from the known values of $|\Delta a|$ and $|\Delta v|$. The rather good agreement between the calculated and observed values of K for Ge, Cd, and Zn suggests that this method has value.

If now, the above procedure for isolating the factors responsible for solution hardening is valid, it should be possible to express the flow stress, σ, for given strains and temperatures directly in terms of

$$\{102 |\Delta a| + 15 |\Delta v| + 7{,}000 |+ 7{,}000 |\Delta a||\Delta v|\} \times (\text{at. pct solute}) \qquad [7]$$

One such plot for atmospheric temperature and a series of strains is shown in fig. 14. Since the data for all of the alloys which were investigated here all fall on a single curve the concept is verified. Other plots of the flow stress vs. the factor of expression (7) for all other strains and all other temperatures that were investigated show similar correlations.

Conclusions

1. Solute elements invariably increase the strength of alpha solid solutions.
2. Additions of solute elements not only increase the initial flow stress but also induce greater rates of strain hardening.
3. The uniform strain in tension testing appears to be only slightly affected by increasing alloying content of the solute element. In general the uniform strain decreases slightly with increasing alloying concentrations of a solute element.
4. The effect of alloying additions in increasing the flow stress of aluminum alloys is more pronounced at atmospheric temperature than at any lower temperature.
5. Lattice strains are one factor involved in solid solution strengthening.
6. Other factors, presumably the difference in valence between the solute and solvent metals, are also present as evidenced by the Al-Ag alloys; silver causes appreciable solution strengthening in spite of the fact that it causes practically no lattice strain when dissolved in aluminum.
7. Equivalent concentrations of the various elements all yield approximately the same stress-strain

curves. The equivalent concentration for each element is a linear function of its atomic percent when the alloying addition is of the magnitude studied in this investigation.

8. The equivalent concentration for any element can be calculated from $E = \{102 \mid \Delta a \mid + 15 \mid \Delta v \mid + 7{,}000 \mid \Delta a \mid\mid \Delta v \mid\} \times$ (at. pct solute) where

Δa = the change in lattice constant per 1 at. pct solute, and

Δv = the change in the number of electrons per atom upon addition of 1 at. pct of the solute.

9. Aluminum appears to contribute about two electrons per atom toward the metallic bond in its alloys.

Acknowledgments

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Many members of the University of California contributed to this investigation. The authors thank Earl R. Parker, A. Goldberg, R. A. Anderson, M. Kawaguchi, A. T. Robinson, T. H. Hazlett and numerous other members who assisted in this program of investigation. In addition they thank Mrs. G. Pelatowski for her careful and exacting work of preparation of the figures in this report.

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TECHNICAL NOTE

The Densification of Pre-Reduced Copper Powder Compacts in Vacuum and in Hydrogen

by Charles B. Jordan and Pol Duwez

A STUDY of the increase in density of copper powder compacts as a function of the time and temperature of sintering has been previously reported.[1] The present note will describe the results of a series of experiments under conditions similar in all respects to those of the first series, except that

CHARLES B. JORDAN is Research Engineer and POL DUWEZ, Member AIME, is Associate Professor of Mechanical Engineering and Chief of Materials Section, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif.

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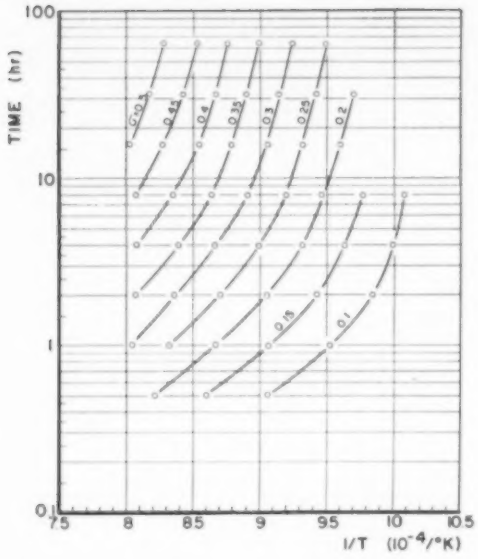

Fig. 1—Relation between time and reciprocal of temperature for various values of densification parameter; vacuum sintering.

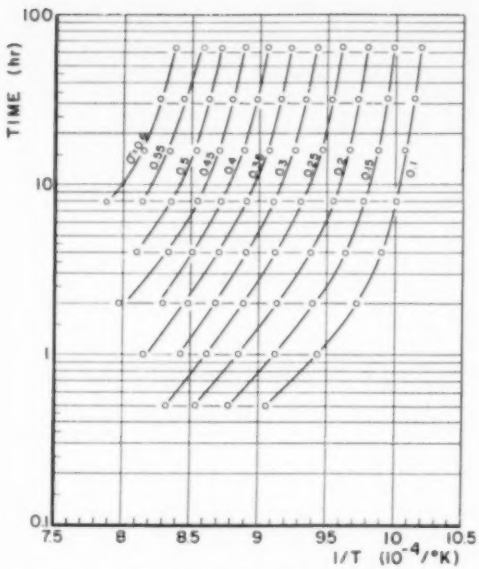

Fig. 2—Relation between time and reciprocal of temperature for various values of densification parameter; hydrogen sintering.

the copper powder was reduced for several hours in hydrogen at 500° or 600°F before pressing.

The results were plotted, as in the previous paper,[1] in terms of the variation of the densification parameter σ as a function of time and temperature. These curves are not qualitatively different from those shown in figs. 1 and 2 of ref. 1, and hence are not given here. The curves of constant σ on a plot of log t vs. $1/T$ (where t represents time and T absolute temperature) are quite different, however, and are shown herewith as figs. 1 and 2. It is at once evident that these curves have a pronounced positive curvature and could not even approximately be represented as straight lines. Correspondingly, the densification of pre-reduced copper powder compacts cannot be described as a rate process governed by a single well-defined heat of activation. In view of this result, it appears that the slight curvature noted in figs. 3 and 4 of ref. 1 is significant.

The situation may be described by stating that the value of Q (the molal heat of activation) increases during sintering, the effect being much more pronounced in the case of pre-reduced copper powder. For the latter case, the values of Q for a sintering time of ½ to 1 hr may be evaluated from the graphs of figs. 1 and 2 to be about 31,000 cal per mol for vacuum sintering, and about 46,000 cal per mol for hydrogen sintering. These values are much lower than those obtained from the straight line approximations of ref. 1, which were 128,000 cal per mol for vacuum sintering and 80,000 cal per mol for hydrogen sintering. The effect of pre-reducing therefore has been to reduce considerably the value of Q at relatively short sintering times. This result is quite reasonable, for the oxide film must impede densification to a degree which is at first large, and decreases progressively as the film is punctured and broken up. It is also of interest to note that for pre-reduced powder Q is lower in hydrogen than in vacuum (for longer time as well as for the short-time values given above), whereas the reverse is true for powder which was not pre-reduced.

Acknowledgment

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Reference

(1) Charles B. Jordan and Pol Duwez: The Densification of Copper Powder Compact in Hydrogen and in Vacuum. *Trans.* AIME, **185**, 96-99, *Jnl. of Met.*, Feb. 1949, TP 2516.

Corrections

In the February 1950 issue: TP 2763 E. *The Extrusion of Powdered Magnesium Alloys* by R. S. Busk and T. E. Leontis. P. 306, fig. 16: The point for 50 Ml + 50 AZ31 (solid black dot) at a stress of 18,000 psi should have an arrow on it pointing to the right and indicating that the bar at this stress did not fail.

In the March 1950 issue: TP 2720 CDE. *The Graphical Representation of Metallurgical Equilibria* by C. J. Osborn. P. 607, fig. 7: The abscissa should read "°K" instead of "°C".

The Properties of Some Magnesium-Lithium Alloys Containing Aluminum and Zinc

by Robert S. Busk, Donald L. Leman, and John J. Casey

The mechanical properties and the phase-temperature relationships of magnesium-lithium-aluminum, magnesium-lithium-zinc, and magnesium-lithium-aluminum-zinc alloys are presented. It is shown that the strengths of some of these alloys can be tripled by heat treating and aging but that the high strength is accompanied by brittleness and lack of stability.

MAGNESIUM-LITHIUM alloys are interesting because the hexagonal structure of magnesium can be changed into the more ductile and workable body-centered cubic structure by the addition of only 10 pct lithium.[1]

After Loonam[2] determined that the ductility of the magnesium-lithium alloys is destroyed by even trace quantities of sodium, it was possible to prepare ductile alloys and study their mechanical properties. Jackson[3] and coworkers have ably described their results with both the binary and polynary magnesium-lithium alloys.

The present paper is a report of the mechanical properties of wrought magnesium-lithium-aluminum, magnesium-lithium-zinc, and magnesium-lithium-aluminum-zinc alloys.

Experimental Procedure

The alloys were made by melting 7 lb of magnesium in a steel crucible under a molten flux of 75 pct LiCl + 25 pct LiF[3] previously dried at 1600°F. The metal was heated to 1300°F for alloying aluminum and zinc and then cooled to 1250°F for adding lithium (sodium content: 0.01 to 0.04 pct). After the lithium had been alloyed, dry LiF powder was sprinkled on the melt to thicken the excess flux. After a 15 min holding period, the flux was skimmed off. Paraffin vapors were used to protect the metal as it was poured into 3 in. diam by 11 in. long magnesium molds.

Billets were extruded into $\frac{3}{8}$-in. diam rod and 1/16x$\frac{3}{4}$-in. strip; sheet was prepared from $\frac{1}{8}$x$\frac{7}{8}$-in. extruded strip, first by hot rolling and then by cold rolling 2 pct per pass. Hot rollability, or the temperature range through which the alloys could be rolled, was determined by rolling the strip two passes at 30 pct reduction per pass. Cold rollability, or the percentage of cold reduction to cause detrimental cracking, was determined on 0.064-in. hot-rolled sheet.

Standard ASTM procedures were followed to obtain the mechanical properties, using 0.2 pct offset for the yield strengths.

The level of properties produced with commercial magnesium alloys using the procedure described is given in a previous publication.[4]

Results

Magnesium - Lithium - Aluminum System: The good workability of magnesium-lithium alloys is illustrated by the data in table I, which shows approximately how the extrusion pressure decreases as the amount of cubic phase increases.

Binary magnesium-lithium alloys are soft and weak, but aluminum raises their strengths con-

ROBERT S. BUSK, Member AIME, DONALD L. LEMAN, and JOHN J. CASEY are associated with the Magnesium Laboratories, The Dow Chemical Co., Midland, Mich.

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TP 2890 E. Discussion (2 copies) may be sent to Transactions *AIME before Dec. 15, 1950. Manuscript received Nov. 29, 1949; revision received April 13, 1950.*

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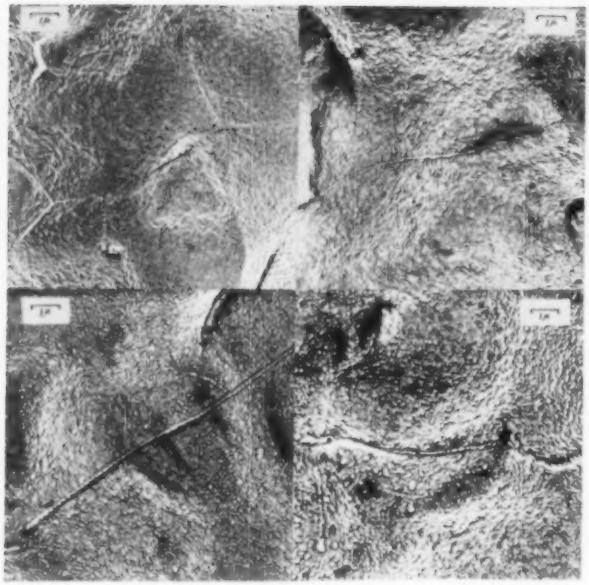

Fig. 1—Electron micrographs of Mg + 12.5 pct Li + 10 pct Al.

Heat treated 1 hr at 700°F, oil quench plus 180°F aging. Methyl iodide etchant. X8000. Reduced approximately one third in reproduction.

	X-ray Data	*Metallography*
a.	Aged at room temperature only	
	Cubic matrix, high AlLi, high MgLi$_2$Al, trace	Rough background Boundary particles Matrix fine ppte.
b.	Aged 4 hr at 180°F	
	Cubic matrix, high AlLi, high MgLi$_2$Al, some	Rough background Boundary particles Matrix fine ppte.
c.	Aged 24 hr at 180°F	
	Cubic matrix, high AlLi, high MgLi$_2$Al, high	Rough background Boundary particles Matrix precipitate
d.	Aged 72 hr at 180°F	
	Cubic matrix, high AlLi, high MgLi$_2$Al, high	Rough background Boundary particles Matrix precipitate

Table I. Initial Pressure Requirement of Magnesium-Lithium-Aluminum Alloys Compared to Commercial AZ80 Alloy

Extrusion Temperature, °F	Extrusion Pressure, psi			
	AZ80* 8.5 Pct Al + 0.5 Pct Zn + 0.2 Pct Mn	3 Pct Li + 9 Pct Al†	7 Pct Li + 9 Pct Al‡	12 Pct Li + 9 Pct Al‡
300	>140,000	>140,000	>140,000	106,000
400	>140,000	>140,000	140,000	70,000
500	140,000	127,000	117,000	46,000
600	90,000	92,000	79,000	31,000
700	64,000	68,000	54,000	
800	52,000			

* 100 pct hexagonal.
† Mixture of hexagonal and cubic.
‡ 100 pct cubic.

siderably as illustrated by the data in table II. The most striking feature of the cubic alloy is its response to a heat treatment at 700°F followed by a rapid quench. The compressive yield strength is raised to levels not yet attained by any other magnesium-base alloy. At the same time, the metal becomes extremely brittle, to the extent that there is failure in tension before any appreciable plastic deformation occurs, resulting in a tensile strength much lower than the compressive yield strength. This extreme hardness and brittleness disappear rapidly after heating at temperatures as low as 180°F; after only 16 hr, the properties are similar to those before heat treatment. These effects persist with 10 pct of hexagonal metal present, but largely disappear when as much as 40 pct hexagonal metal is present.

The three characteristics of hardening upon heat treating and quenching, of extreme brittleness associated with high strength, and of lack of stability of the high-strength levels upon heating at low temperatures are all typical of magnesium-lithium-aluminum alloys of predominantly cubic structure.

Table III gives data for a series of magnesium-lithium-aluminum alloys, including wholly hexagonal (3 pct lithium), hexagonal plus cubic (7 pct lithium and 9 pct lithium) and wholly cubic (12.5 and 16 pct lithium) types. Compressive yield strengths greater than 60,000 psi and values as high as 74,000 psi are obtained. This degree of hardening depends upon both proper lithium and aluminum contents. As also noted by Jackson,[2] increasing lithium increases stability. Thus when 16 pct lithium is used, the values obtained after quenching are more stable than those obtained with 12 pct lithium, but the metal is very brittle. The data for cold-rolled metal are interesting in that the wholly cubic metal is not hardened by rolling at room temperature. This also was discussed by Jackson[2] and is generally true of cubic magnesium-lithium type alloys.

The source of the hardening, brittleness, and instability of these alloys was investigated. It was considered that the hardening was most probably

Table II. Effect of Hexagonal Phase on Properties of Extruded Magnesium + Lithium + 6 pct Aluminum Alloys

Actual Composition		Pct Hexagonal Phase	Treatment*	Pct E	1000 psi		
Pct Li	Pct Al				TYS	CYS	TS
11.4	6.3	0	As extruded	10	41	40	44
			1 hr 700°F	0		67	44
			1 hr 700°F + 16 hr 180°F	10	34	37	43
			1 hr 700°F + 48 hr 180°F	20	31	31	40
10.4	6.5	10	As extruded	6	40	42	43
			1 hr 700°F	2	46	62	52
			1 hr 700°F + 16 hr 180°F	17	35	38	46
			1 hr 700°F + 48 hr 180°F	23	34	32	43
9.9	5.5	40	As extruded	10	39	42	
			1 hr 700°F	10	42	51	44
			1 hr 700°F + 16 hr 180°F	25	30	34	50
			1 hr 700°F + 48 hr 180°F	23	29	33	40 40

* Properties are for $\frac{3}{8}$-in. rod extruded at 450°F. The 700°F heat treatment was followed by a water quench.

Table III. Properties of Magnesium-Lithium-Aluminum Alloys

Nominal Composition		Extruded Properties (1000 psi)						Cold Rolled Properties									
		⅜ In. Rod Comp. Yield Strength		1 1/16x3/4 In. Strip 5 Ft per Min						1000 psi					1000 psi		
Pct Li	Pct Al	Heat Treated*	Heat Treated* 16 Hr 180°F	Pct E	TYS	CYS	TS	Pct Cold Roll	Pct E	TYS	CYS	TS	Pct Cold Roll	Pct E	TYS	CYS	TS	Cold Rollability, Pct Cold Roll
3	3	17	18†	23	20	17	33	10	7	39	30	46	30		44	37	45	39
3	6	21	23†	20	26	22	40	10	6	44	36	51	10			44	46	25
3	9	26	35†	12	33	29	47	3	6	39	32	48	9			40		12
7	3	22	23†	17	27	29	34	10	4	38	37	43	30	3	42	40	48	47
7	6	29	32†	9	28	32	38	10	5	43	42	49	20	2	44	45	50	33
7	9	32	36†	6	31	33	40	10	1	44	44	49	20			43		23
9	3	31	22	13	34	34	38	28	13	30	29	34	66	12	29	32	35	‡
9	4	36	28	10	35	37	41	28	11	32	32	40	66	10	33	35	39	‡
9	6	33	32	9	34	37	41	28	8	35	35	42	66	6	33	35	41	‡
9	8	39	34	6	36	39	42	28	5	34	34	41	66	1	32	37	37	‡
9	10	36	34	5	36	39	42											70
9	12	35	34	3	36	40	45											32
12.5	2	29	24	16	31	35	35	28	15	26	25	29	66	13	23	25	27	‡
12.5	4	49	32	17	31	34	36	28	15	25	26	29	66	17	24	27	29	‡
12.5	6	67	39	13	32	35	36	28	18	27	23	31	66	15	25	28	30	‡
12.5	8	67	40	12	30	33	35	28	18	26	27	31	66	15	25	28	29	‡
12.5	10	73	41	6	32	36	37	28	12	25	26	30						‡
12.5	12	74	40	3	33	34	37	28	10	24	25	30	66	11	25	28	30	‡
16	2	14	18	15	17	20	23	28	9	24	24	26	66	8	25	26	28	‡
16	4	29	33	6	28	34	33	28	11	25	25	29	66	10	26	26	30	‡
16	6	42	48	12	32	35	36	28	13	27	26	31	66	12	27	29	33	‡
16	8	51	55	7	31	34	35	28	12	27	27	31	66	12	27	28	34	‡
16	10	52	57	6	33	37	38	28	24	28	28	32	66	10	28	29	35	‡
16	12	54	52	4	32	34	37	28	8	28	28	33	66	6	28	29	35	‡

* Heat treated 1 hr at 700°F.
† 150 hr at 150°F.
‡ Greater than 70 pct.

an age-hardening phenomenon and X-ray diffraction was used to determine whether any phases were present that would be expected to contribute to the hardening found. Table IV gives the phases found as a function of heat treatment for a magnesium + 12.5 pct lithium + 10 pct aluminum alloy. AlLi is a body-centered cubic compound with a B32 structure (NaTl type). $MgLi_2Al$ is derived from the B32 (AlLi) structure by replacing half of the aluminum atoms by magnesium atoms. It was assigned the tentative formula MgLi · LiAl by Jackson.[3] It is believed that $MgLi_2Al$ is the hardening phase since analysis of reflections from single grains showed that the (100) planes for $MgLi_2Al$ are parallel to the (100) planes for the magnesium-lithium solid solution, and since the lattice dimensions of $MgLi_2Al$ differ from the matrix by about 5 pct.

Table IV shows that under equilibrium conditions this composition is apparently single phase (cubic solid-solution) above 750°F, is two phase (cubic solid-solution plus AlLi) from 300° to 750°F, and also two phase below 225°F (cubic solid-solution plus $MgLi_2Al$). Assuming this is correct, there must be a three phase region between 225° and 300°F. This most probably consists of cubic solid-solution, $MgLi_2Al$, and AlLi. It is believed that the poor property stability at low temperatures is related to the low temperature at which the hardening phase ($MgLi_2Al$) transforms to AlLi.

When the magnesium + 12.5 pct lithium + 10 pct aluminum alloy is in the fully hardened condition, the brittle fracture is at the grain boundary. One specimen was prepared with a grain size of 0.05 in., heat treated 1 hr at 700°F, quenched, and fractured. A single grain was then removed from the fractured surface. This grain could be compressed to a flat disc without cracking. A second grain was removed, compressed 10 pct, sealed in an evacuated tube, reheated 15 min at 700°F, and quenched. When this grain was compressed, it fractured immediately along the new boundaries formed by recrystallization and grain growth. Once the fractures had separated the grains, each individual grain compressed without further cracking. Thus the cause of embrittling is localized at the grain boundary and is something that forms as the boundaries are produced.

Analyses of etching solutions that had been in contact with fractured and sawed surfaces of both brittle and ductile material, indicated that there is a tendency for the fracture of the brittle alloy to seek out higher sodium regions. Since the fracture is at the grain boundary, there is apparently some concentration of sodium at the grain boundaries.

The electron micrographs in fig. 1 give evidence of the concentration of something at the grain boundaries.

Table IV. X-Ray Diffraction Data on a Magnesium + 12.5 pct Lithium + 10 pct Aluminum Alloy ⅜-in. rod extruded at 450°F—3 ft per min.

Heat Treatment*	Phases Present	
	AlLi a_o = ~6.40Å	$MgLi_2Al$ a_o = ~6.7Å
1 hr 700°F	High	Trace
1 hr 700°F + 24 hr 225°F	High	High
1 hr 750°F	None	High
1 hr 800°F	None	High
1 hr 800°F + 24 hr 225°F	None	High
1 hr 800°F + 1 hr 300°F	High	Trace
1 hr 800°F + 1 hr 400°F	High	None
1 hr 800°F + 1 hr 500°F	High	None
1 hr 800°F + 1 hr 600°F	High	None
1 hr 800°F + 1 hr 700°F	High (Somewhat lower)	Trace

* All specimens were quenched in cold water after a heat treatment higher than 300°F.

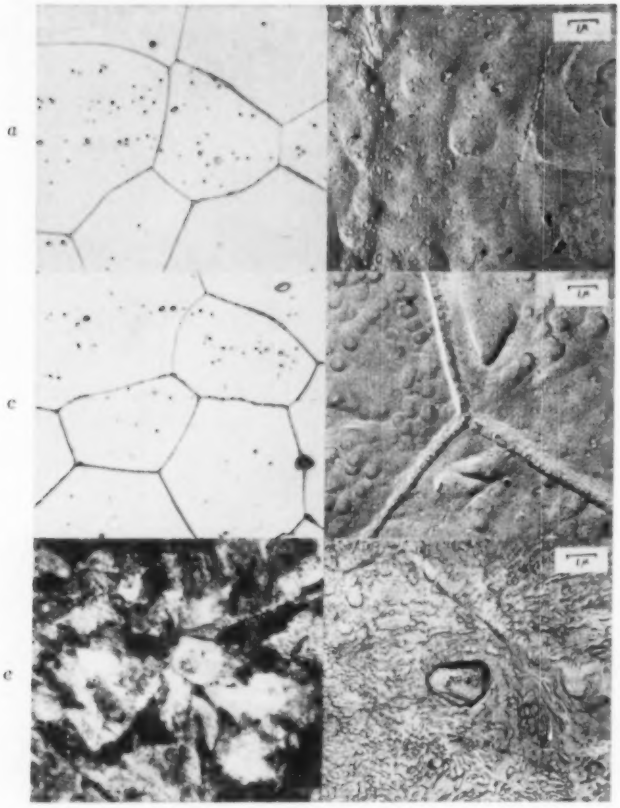

Fig. 2—Structure of Mg + 5 pct Li + 4 pct Al + 3 pct Zn. Solution heat treated and aged condition.

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a, c, e. Photomicrographs. Phospho picral etchant. X1000.
b, d, f. Electron micrographs. Methyl iodide etchant. X8000.
a, b. Hot rolled + ½ hr at 700°F.
c, d. Hot rolled + ½ hr at 700°F + 24 hr at 225°F.
e, f. Hot rolled + ½ hr at 700°F + 1 hr at 400°F.

Table V. Properties of Magnesium-Lithium-Zinc Alloys

Nominal Composition		As Extruded*				Heat Treated†				HT + 5 days 95°F				HT + 18 hr 180°F				Hot Rollability	Cold Rollability,
			1000 psi				1000 psi				1000 psi				1000 psi				
Pct Li	Pct Zn	Pct E	TYS	CYS	TS	Pct E	TYS	CYS	TS	Pct E	TYS	CYS	TS	Pct E	TYS	CYS	TS	Rolling Range (°F)	Pct Cold Roll
3	3	25	20	19	33			10				10						300-700	53
3	6	23	24	24	38			12				12						400-600	45
3	9	20	27	27	41			17				17						400-600	41
7	3	26	22	25	29			17				19						200-600	>70
7	6	20	27	28	35			27				27						200-600	>70
7	9	16	28	29	36			30				33						200-600	>70
7	12	11	30	33	37	1	47	38	58					28	30	32	43	200-600	
7	14	9	39	40	46	2	46	47	66	5	49	45	63	26	32	35	44	200-600	
7	16			40		1	60	52	67	2	52	49	64	25	30	33	43	200-600	
7	20	3	44	44	51	0	60	62	65	1	59	53	70	12	34	37	48	300-600	
7	25	2	46	47	50	0		75	59	0	54	70	64	9	35	35	45	400-600	
7	35	1	52	56	55	0		86	51	0		78	58	2	37	39	44	500-600	
10	3	5	49	54	53	3	43	43	46					35	25	26	32	200-600	
10	10	5	48	54	52	0		50	46					35	26	28	33	200-600	
10	12	4	50	52	54	0		53	38					29	23	29	37	200-600	
10	14	5	52	57	58	0		60	41	0		59	37	30	29	33	39	200-600	
10	16	5	51	53	57	0		74	35	0			34	20	34	36	42	200-600	
10	20	4	50	54	56	0		74	33	0			32	5	37	41	49	200-600	
10	25	2	42	40	48	0		68	40	0		81	45	11	37	38	49	300-600	
10	35	0		51	47	0		71	35	0		63	39	0.5	38	41	46	600-600	
12	3	31	19	19	24			15				17						200-600	70
12	6	16	31	44	36			20				35						200-600	70
12	9	2	45	50	49			35				53						200-600	70
12	10	6	46	47	50	4	35	35	37					28	26	29	34	200-600	
12	12	6	43	54	46	0		43	34					25	29	32	38	200-600	
16	6	21	17	18	24	24	16	17	23					25	17	17	25	200-600	
16	8	19	19	20	26	17	18	19	25					24	18	19	25	200-300	
16	10	17	21	22	28	14	20	21	26					23	20	21	28	200-300	
16	12	15	23	24	30	9	23	23	27					22	22	23	30	200-300	

* Rod extruded at 5 ft per min at 450° to 500°F.
† Heat treated or HT = ½ hr 700°F, cold water quench.

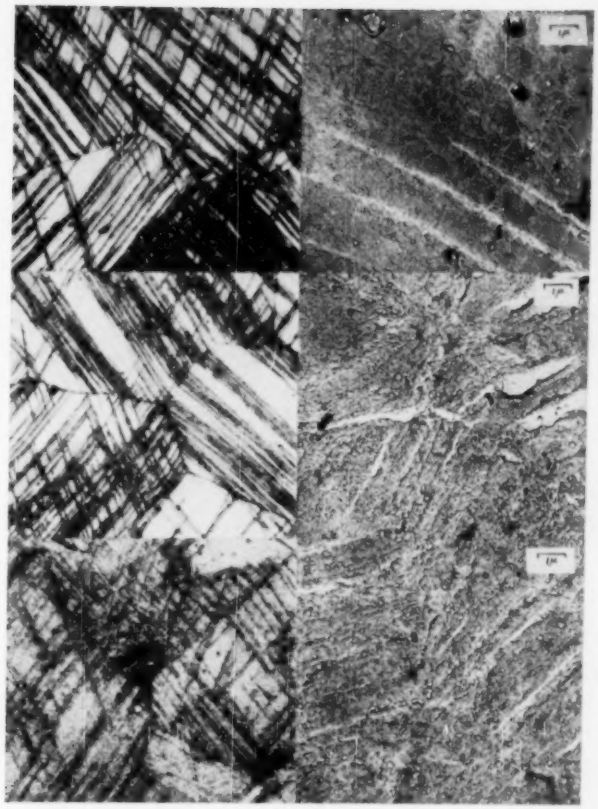

Fig. 3—Structure of Mg + 5 pct Li + 4 pct Al + 3 pct Zn. Solution heat treated, cold rolled, and aged condition.

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a, c, e. Photomicrographs. Phospho picral etchant. X1000.
b, d, f. Electron micrographs. Methyl iodide etchant. X8000.
a, b. Hot rolled + ½ hr at 700°F + 10 pct cold roll.
c, d. Hot rolled + ½ hr at 700°F + 10 pct cold roll + 24 hr at 225°F.
e, f. Hot rolled + ½ hr at 700°F + 10 pct cold roll + 1 hr at 400°F.

These experiments, it is believed, show that the brittleness is due to an envelope of AlLi and some concentration of sodium at the grain boundary. The adherence of this envelope to the matrix has a finite value, and if the proportional limit of the metal is below this value, plastic deformation can occur. If, however, the proportional limit of the metal is above this value, separation at the grain boundary will occur before plastic deformation can take place.

Table VI. X-Ray Diffraction Data on a Magnesium + 7 pct Lithium + 16 pct Zinc Composition
¾-in. rod extruded at 450°F—3 ft per min

Heat Treatment*	Phases Present	
	MgLiZn a_o = ~7.46A	$MgLi_2Zn$ a_o = ~6.7A
½ hr 750°F (base)	Very low	High
Base + 24 hr 225°F	Very low	High
Base + 1 hr 300°F	Very low	High
Base + 1 hr 300°F + 24 hr 225°F	Very low	High
Base + 1 hr 400°F	High	Trace
Base + 1 hr 400°F + 24 hr 225°F	High	Trace
Base + 1 hr 500°F	High	Low
Base + 1 hr 500°F + 24 hr 225°F	High	Low
Base + 1 hr 600°F	High	Medium
Base + 1 hr 600°F + 24 hr 225°F	High	Medium
Base + 1 hr 700°F	High	Medium
Base + 1 hr 700°F + 24 hr 225°F	High	Medium

* All specimens were quenched in cold water after a heat treatment higher than 225°F.

Magnesium-Lithium-Zinc System: Although the properties of the magnesium-lithium-zinc system (table V) are similar in most respects to those of the magnesium-lithium-aluminum, there are some differences. The hardening reaction is prominent even in the presence of 50 pct hexagonal metal; the strengths are higher; and the alloys are less brittle. Electron micrographs show that the grain boundaries are cleaner than those in the magnesium-lithium-aluminum alloys.

The X-ray data given in table VI show the magnesium-lithium-zinc system to be analogous in every respect to the magnesium-lithium-aluminum system with replacement of MgLiZn for AlLi and $MgLi_2Zn$ for $MgLi_2Al$.

Magnesium - Lithium - Aluminum - Zinc System: The alloys of the quaternary system are different from either of the ternary systems in that the most interesting compositions are mainly hexagonal. These alloys respond to the technique of heat treating, and then cold working followed by aging, as

Table VII. Properties of Rolled Magnesium-Lithium-Aluminum-Zinc Alloys

Nominal Composition			Rolled Properties								Hot Rollability	Cold Rollability
			Heat Treated*				Heat Treated + Cold Rolled + 48 Hr 225°F					
				1000 psi				1000 psi				
Pct Li	Pct Al	Pct Zn	Pct E	TYS	CYS	TS	Pct E	TYS	CYS	TS	Rolling Range (°F)	Pct Cold Roll
3	0	1	23	13	12	24	16	23	19	26	200-700	71
3	0	3	27	16	11	27	15	27	22	34	200-700	48
3	2	0	24	20	15	29	13	28	24	34	300-700	55
3	2	1	24	21	15	30	14	31	27	38	300-700	45
3	2	3	22	23	15	33	11	36	34	44	400-600	38
3	4	0	22	23	15	34	12	34	28	41	400-700	40
3	4	1	20	24	15	34	16	34	31	42	400-700	38
3	4	3	19	27	17	37	10	41	38	49	400-600	29
5	0	1	30	13	13	22	18	21	23	27	200-700	68
5	0	3	28	17	13	28	14	28	29	33	200-700	47
5	2	0	24	17	16	27	15	25	26	32	200-700	54
5	2	1	24	19	17	30	25	29	30	37	300-700	45
5	2	3	21	26	20	36	13	38	36	44	400-700	35
5	2	7	17	32	23	42	3	43	44	52	400-700	29
5	4	0	21	23	18	32	14	33	33	40	300-700	37
5	4	1	20	25	19	34	13	38	37	44	300-700	33
5	4	3	17	30	22	39	6	45	45	53	400-600	29
5	4	7	13	34	29	43	2	49	51	56	400-600	26
5	6	3	15	32	24	41	3	49	49	54	400-600	26
5	6	7	12	34	30	44	2	47	51	54	400-600	25
5	8	1			26		1	42	48	52	400-600	23
5	8	3	12			50	1	49	52	55	400-600	23
5	8	7	11		31	47	0		56	39	400-600	24
5	8	12	3		40	46	0		61	42	500-600	18
5	10	5	9	36	31	49	0.5	53	57	60	400-600	22
5	12	5	6	38	34	51	0		58	34	500-600	23
7	2	3	15	27	32	41	14	33	34	41†	200-600	49
7	2	7	8	34	34	49	13	36	39	47	200-600	36
7	4	3	7	33	32	46	6	35	42	49	200-600	36
7	4	7	2	39	40	53	3	42	43	54	200-600	30
7	6	6	15	30	25	39	2	37	43	46	400-600	33
7	6	3	10	36	34	46	2	46	47	53	300-600	29
7	6	7	7	32	35	47	3	38	44	51	300-600	28
7	8	1	6	31	33	43	0.5	46	53	51	400-600	29
7	8	3	6		31	41	1	48	52	55	400-600	26
7	8	7	5	34	36	44	1	50	55	56	400-600	25
7	8	12	2	39	42	48	0		58	35†	500-600	22
7	12	5	4		37	46	1	51	55	55	500-600	28
9	2	3	12	41	43	43	16	25	28	34	200-600	64
9	2	7	3	56	59	58	21	32	30	39	200-600	63
9	4	3	3	51	56	57	15	31	31	39	200-600	49
9	4	7	0.5	59	59	60	7	33	33	45†	200-600	5
9	6	3	4	46	47	53	11	29	32	39	200-600	33
9	6	7	1	51	52	60	6	36	37	47†	200-600	10
9	8	1	2	42	42	54	3	35	38	44	300-600	23
9	8	3	2	43	41	53	3	33	37	44	300-600	23
9	8	7		54	55	60	3	32	36	45	300-600	13
9	8	12	0.5	53	52	63	2	34	41	47	300-600	8
9	10	5	3	37	36	51	1	37	44	48	400-600	23
9	12	5	2	37	37	51	1	42	45	48	400-600	24

* Heat treated, ½ hr 700°F, cold water quench.

† Aged 24 hr at 225°F.

illustrated by the properties of a magnesium + 5 pct lithium + 2 pct aluminum + 5 pct zinc alloy:

			1000 psi		
		Pct E	TYS	CYS	TS
1.	Extruded + ½ hr 700°F + water quench	24	26	25	38
2.	No. 1 + 48 hr at 180°F	22	26	22	40
3.	Rolled + ½ hr 700°F + 10 pct cold roll	12	39	35	46
4.	No. 3 + 48 hr at 180°F	11	42	41	49

The hardening phase in these alloys is (Al,Zn)Li, a compound with the same structure as AlLi but containing an indefinite amount of zinc.

Marked differences exist between the hardening produced by aging directly from the solution heat-treated condition and that produced by cold rolling before the aging treatment. Fig. 2 shows the lamellar precipitate of (Al,Zn)Li, the formation of which is associated with little or no strengthening and a decrease in the percentage of elongation. However, strength does increase on aging metal which has been cold rolled. The precipitate is now in the form of discrete globular particles as shown in fig. 3. Thus the (Al,Zn)Li phase can be made a hardening constituent in the magnesium-lithium-aluminum-zinc alloys.

The properties of a number of magnesium-lithium-aluminum-zinc alloys are given in table VII. Maximum properties in the cold-rolled and aged conditions occur at 5 and 7 pct lithium. When 9 pct lithium is used, the characteristics noted for the ternary systems are apparent. Maximum strength is obtained upon heat treating and quenching and the high-strength levels are not stable for extended periods at low temperatures.

Although many of these alloys have stable strength and elongation values superior to those of the high-strength commercial sheet alloy AZ31h, they have low notch toughness. Magnesium + 5 pct lithium + 4 pct aluminum + 3 pct zinc, at a level of 45,000 psi tensile and compressive yield strength, has a notch bend energy value of 2.5 in.-lb. Even when processed to a strength level comparable to that of AZ31h, the toughness is less than 11 in.-lb, the typical value for AZ31h.[5]

The stress corrosion sensitivity of the magnesium-lithium-aluminum-zinc alloys is also below normal. The sustained stress which will not cause failure for an extended period of time is less than 10,000 psi. This value was determined in a rural atmosphere using the spring-load tension test described by Loose and Barbian.[6]

Summary

1. Lithium increases the workability of magnesium-aluminum, magnesium-zinc, and magnesium-aluminum-zinc alloys. This increase is caused by the cubic phase that lithium produces.

2. Magnesium-lithium-aluminum alloys have very high strengths in the hardened state accompanied by extreme brittleness and lack of stability on heating at temperatures as low as 180°F. Magnesium-lithium-zinc alloys are similar except that they are less brittle.

3. The precipitation of $MgLi_2X$ (where X is aluminum or zinc) on quenching from solution heat-treated condition produces the high hardness of these alloys. The property instability is due to low-temperature agglomeration and growth of the $MgLi_2X$ phase which is unstable above 300°F.

4. A continuous envelope of AlLi at the grain boundaries causes the extreme brittleness of magnesium-lithium-aluminum alloys. A concentration of sodium at the grain boundaries is believed to contribute to the brittleness of both magnesium-lithium-aluminum and magnesium-lithium-zinc alloys.

5. Stable high-strength properties, with good elongation but low toughness, can be obtained in hexagonal magnesium-lithium-aluminum-zinc alloys by precipitation of (Al,Zn)Li induced by heat treating and cold rolling.

6. While many of the alloys studied have properties superior to those of commercial magnesium alloys, further development awaits solution of the problems of temperature stability, brittleness, stress corrosion, and low toughness at intermediate strengths.

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TECHNICAL NOTE

Correlation Between Electrical and Thermal Conductivity in Nickel and Nickel Alloys

by Morris E. Fine

THE electrical conductivity (σ) and the thermal conductivity (K) of metallic conductors, as demonstrated by Smith and Palmer[1] and Hume-Rothery,[2] are to a good approximation related by an empirical equation, $K = A\,\sigma\,T + B$, in which T is the absolute temperature, and A and B are constants, the Lorenz constant and the lattice conductivity. Strictly speaking, the lattice conductivity is not a constant, but to some extent depends upon the electronic conductivity.[3] By plotting K as a function of σT, this equation has been proved to a

MORRIS E. FINE, Member AIME, is associated with Bell Telephone Laboratories, New York, N. Y.

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good approximation for copper,[3] iron,[4] aluminum,[5] and magnesium[6] alloys. Such plots are valuable because they enable calculation of an approximate value for the difficultly measured thermal conductivity.

Fig. 1 is a K-σT plot for nickel and a number of nickel alloys derived from data existing in the literature. The deviations of the data from the straight line in fig. 1 compare favorably with the deviations observed by Smith and Palmer[1] for copper alloys.

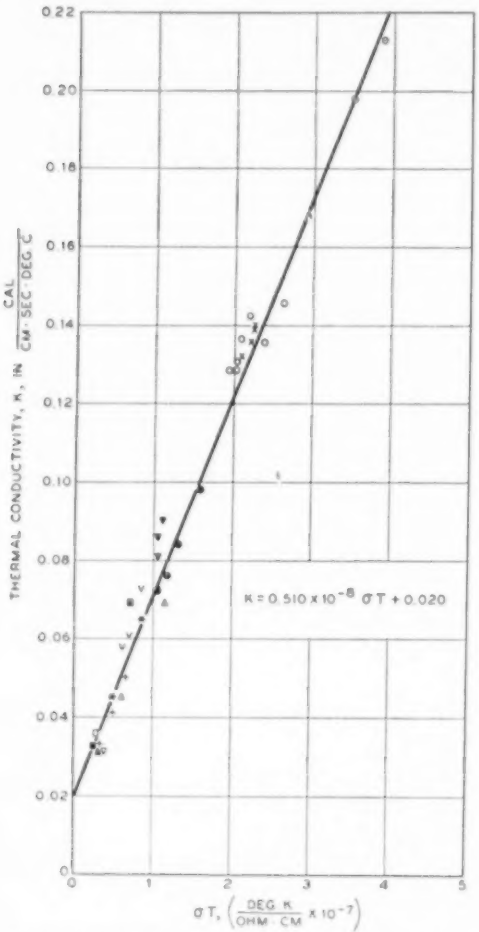

Fig. 1—Relation between thermal conductivity and product of electrical conductivity and absolute temperature in nickel and nickel alloys.

With several exceptions the deviations are less than $0.01 \frac{\text{cal}}{\text{deg C cm sec}}$. The compositions (all face-centered cubic), temperature ranges, and sources of the data are given in table I. Deviations are expected at very low temperatures especially in pure metals.[7, 8] In nickel, according to the data of Lees,[8] the deviations become important below —125°C. Deviations are also predicted for nickel and other transition metals at high temperatures. Schoffield's[10] data for nickel deviate increasingly from the straight line of fig. 1 as the temperature is raised above 304°C. However, at 691°C the deviation amounts only to $0.011 \frac{\text{cal}}{\text{deg C cm sec}}$. No unusual deviations are noted for any of the alloys for which high-temperature points are plotted.

Application of the free electron theory of metals to the electronic conductivities[7, 8] gives $0.581 \times 10^{-8} \frac{\text{cal ohms}}{(\text{deg C})^2 \text{ sec}}$ for A, the ratio between the electronic thermal conductivity and the product of the electrical conductivity and absolute temperature. The observed value in copper alloys is 0.571×10^{-8}. The value for A in nickel alloys, 0.510×10^{-8}, is in good agreement with these. The observed lattice conductivity in nickel alloys, $0.020 \frac{\text{cal}}{\text{deg C cm sec}}$, is nearly the same as the value 0.018 observed in copper alloys.

Table I. Legend for Fig. 1

Symbol	Alloy	Temp. Range	Reference
●	99.9 Ni	40 to 100°C	11 and 15
○	99.2 Ni	0 to 691°C	10
×	99 Ni	-125 to 18°C	9
▲	98.5 Ni	32°C	14
■	2 Al, 2 Mn, 1 Si	100 to 500°C	11 and 12
▼	20 Cu	44 to 198°C	16
▽	40 Cu	52 to 194°C	16
▲	33 Fe, 13 Cr, 1.4 Mn, 0.45 Si	15 and 1000°C	13
■	30 Cu	54°C	17
●	10 Cr	100 to 500°C	11 and 12
+	20 Cr	100 to 500°C	11 and 12
△	23 Fe, 16 Cr	100 to 500°C	11 and 12
□	20 Cr	32°C	14
■	26 Fe, 12 Cr	32°C	14
▽	13.4 Cr, 8.5 Fe	15°C	13

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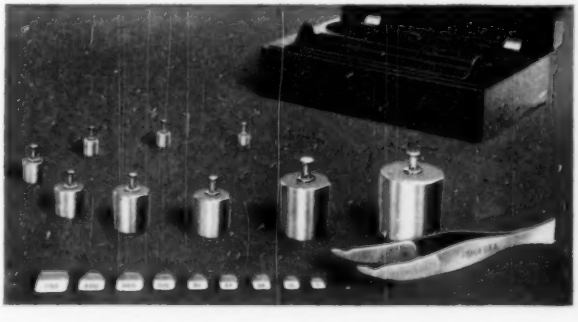

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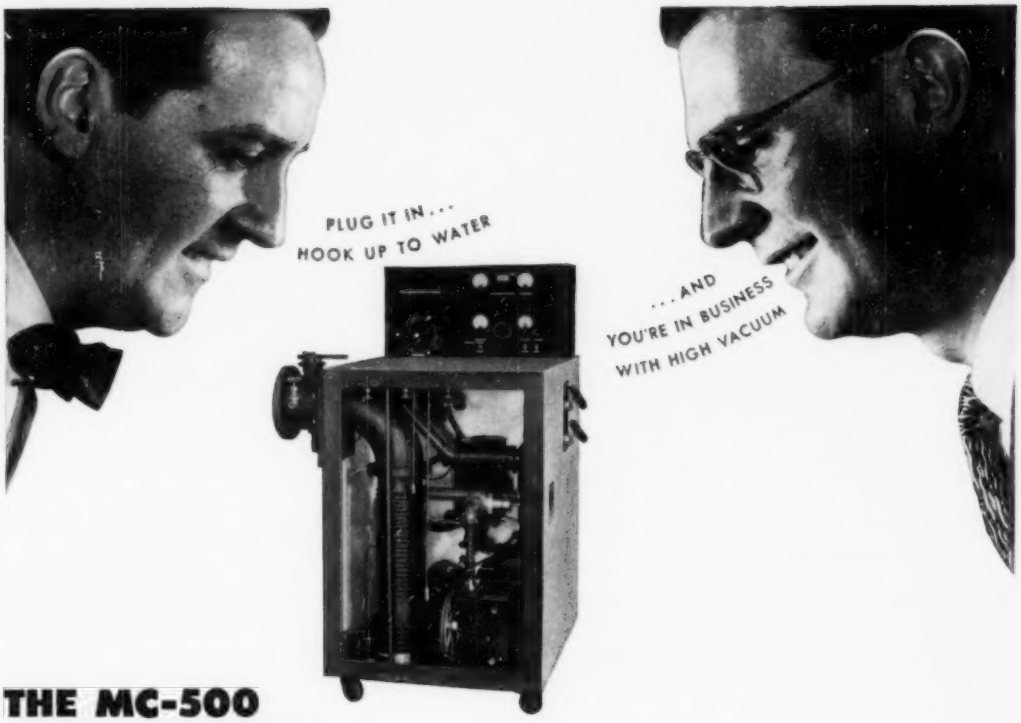

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